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EDITORIAL

With this issue the *Journal* becomes bi-monthly instead of quarterly, and the *Bulletin* disappears. For some time the two publications have overlapped, and the *Bulletin's* original duty of announcing meetings is now carried out more economically by specially printed leaflets.

We believe that our members will approve of this step, which has many advantages. It will enable us to concentrate our resources on the one publication, and will make possible many new features which will add greatly to the *Journal's* value as well as to its general interest. It will also result in a very substantial saving in postage and distribution costs.

As before, the main function of the *Journal* will be the presentation, in permanent form, of the papers delivered at meetings. The enlargement of size should now make it possible to have a more balanced and varied issue, and a number of regular features are planned for the future. Amongst them are reports of meetings, biographical sketches of contributors, and a better coverage of important books and news items. We also hope to publish more news of the American societies with whom we are in close contact.

Under the new arrangement, our members will receive in a more convenient form at least as much printed material as before, and we hope steadily to increase the size of the *Journal* as our membership list lengthens. Even now we believe that we are publishing more material than any other astronautical society in the world, and despite current difficulties and restrictions we will make every effort to maintain that position.

Lecture Programme: Session 1947–48

The following changes to the Society's published lecture programme have been approved by the Council:—

(*a*) The lecture entitled "High Strength Hydrogen Peroxide for Rocket Propulsion," to be given by V. W. Slater, *B.Sc., F.R.I.C.*, and W. S. Wood, *B.Sc., F.R.I.C., A.M.I.Chem.I.*, will not now be held at St. Martin's Technical School. In view of the outstanding importance of this subject and to enable all those who wish to hear the lecture to attend, advantage has been taken of the greater facilities available at the Lecture Theatre of the Science Museum, South Kensington, kindly made available by permission of the Director.

The lecture will commence at 7 p.m. and not 6.30 p.m. as advertised.

(*b*) The lectures on the following dates will commence at 7 p.m. and not 6.30 p.m. as previously announced:—

Wednesday, 7th January, 1948.
Friday, 5th March, 1948.
Wednesday, 5th May, 1948.

The Secretary will be very pleased to hear from provincial and overseas members who would like to put questions to the "Brains Trust" at the meeting on 5th March, 1948.

CONDITIONS ON THE SURFACE OF MARS

By M. W. WHOLEY

A paper read to the British Interplanetary Society in London on 16th August, 1947

Historical

When the ice of interplanetary travel has been broken, and the majority of people have recovered from their surprise at the successful return of a Lunar Expedition, then will man's questing spirit turn to the first of the planetary targets. Of the two nearest—Venus and Mars—it is probable that Mars, although the farther away of the two, will be chosen for a number of good reasons. One reason is that Venus is also the nearer to the Sun, being between ourselves and Mercury. In this orbit relative to ourselves it exhibits a series of phases similar to those of the monthly cycle of the Moon, but unfortunately the "full-moon phase" of Venus occurs when it is on the opposite side of its orbit to ourselves. On the other hand, when at its nearest approach to the Earth the most that can be seen is a thin uniform band of light, referred to as the "Twilight Belt," caused by the refraction of sunlight around the limb of the planet by its atmosphere. A similar belt would be observed around the Earth by a person on the surface of Mars.

In addition to this, Venus has an almost perpetual cloud layer, which only at rare intervals has permitted even the vaguest suggestion of surface markings to be seen. A vessel attempting a landing on Venus with the present degree of knowledge of its surface would be courting disaster at the outset. In order to design the ship it is obviously necessary at the earliest stage to have some knowledge of the surface upon which landing is to take place; hence, for the present, Venus is not a practicable target.

On the other hand, Mars offers wider possibilities. At its closest approach to the Earth the planet exhibits its full surface in the Sun's reflected light, and decades of telescopic investigation, with instruments of increasing size and efficiency, have resulted in the accumulation of a large quantity of knowledge which, when pieced together, provides a basis for much serious speculation. In fact, nearly all the disc is visible in whatever position Mars appears when seen from the Earth. The only diversion from this aspect occurs when Mars moves to positions farthest out of line with the Sun in relation to ourselves. In the case of planets farther away from us, i.e. outward from the Sun, this effect becomes less and less as the subtended angles of the planets diminish.

Mars, throughout the telescopic era, has lived up to its classical name. As a battle ground for speculation it has fully rivalled almost every other individual astronomical divergence of opinion since Fontenelle. Matters really came to a head in the 19th century. It started with Darwin's *Origin of Species by Natural Selection*, which inferred that life would generate wherever the conditions were suitable, and, by the system of natural selection, produce intelligent beings. These beings would probably develop to a similar degree during the same period of time in any two places where conditions were similar.

Secondly, the extreme plausibility of the new "Laplace Nebula Theory" of the formation of the Solar System, convinced people that this explanation

was somewhere near the truth, and from it followed a trend of logic in this vein—the whirling mass of gas forming the Nebula became first an oblate globe, then a lens shape—and finally condensing and cooling from the outside inwards, starting with (the then unknown) Pluto and ending with the Sun. Hence Mars, which was next in order *outwards* from the Sun in relation to ourselves, was, to a certain degree, older in formation, and Venus, the next inwards to the Sun, was younger.

Given the Natural Selection Theory and the Nebula Theory, it was but a short step to the belief that life on Venus must be of a lower form than on Earth and probably of a primeval type; whereas that on Mars must be in a much more highly developed state.

Even at that time it was apparent that Venus was covered in some kind of cloud layer, a fact which seemed to fit into place in considering the evolutionary trend of the Earth's development. The clouds were obviously those covering the steaming, primeval swamps of a young planet, and life on such a planet must necessarily be of a very low order indeed.

There was required but one thing—corroboratory evidence from the planet Mars.

Dramatically enough, evidence was forthcoming at the psychological moment—from Italy. The astronomer Giovanni Schiaparelli in 1877 announced that he had observed on the face of Mars fine markings in the form of straight lines which he termed "Canali." In spite of the fact that the Italian word "Canali" means "grooves" or "channels" and only in a colloquial manner "canals," the world, with its unfinished jigsaw puzzle upon its lap, promptly and definitely translated "Canali" as "canals." It seized the result with ardour, excitedly discussing this proof of a great intellect on Mars in such vast feats of engineering. (Some of the "canals" were of the order of 100 miles wide.) At last here was the evidence they wanted, and its addition to the puzzle completed a very plausible picture. Here were beings faced with extinction as their atmosphere combined with the surface minerals of the planet and escaped into space, taking most of the water supply with it. Obviously the greater technological knowledge of the inhabitants had made possible the solving of this problem. A network of canals of varying sizes covered the planet from pole to pole and distributed the remaining water from the Ice Caps to the rest of the planet.

Arguments against the apparent width of some of the canals were quashed by hypotheses which explained that probably the "canals" were in reality very narrow or were even underground pipelines to prevent evaporation, and the dark markings were irrigated strips similar to the Nile Valley. This more or less completed the argument and enthusiasm grew. In the astronomical world Percival Lowell took up the challenge of the sceptics and by the turn of the last century a battle royal was in progress, and to a certain extent still continues to-day, though other factors have intruded which now make the acceptance of a "super-intelligent inhabitant" hypothesis more doubtful.

The Martian Terrain

Although the chances of finding highly intelligent life on Mars have been diminished, it is quite possible that life of several plant and animal types may exist.

For the present we will consider merely the surface of the planet. As the main object of this survey is to give some idea of the conditions likely to be encountered by the first expedition, it might be helpful to imagine yourself a member of such a party. The ship has just reached terminal velocity and we can leave our "inertia couches." Space around would be utterly black, with a startling velvety appearance, pierced by many more stars than can be seen from the Earth's surface. These stars would be extremely brilliant, with no sign of twinkling, and would give the scene a peculiarly frozen look. The different types of stars would exhibit distinct differences in colour.

The Sun itself would be transformed from a yellow ball to a most remarkable sight—unbearably bright—its Corona (usually seen only during an eclipse, or through a coronograph) would be clearly visible for the split second a person could bear to look at it. The Zodiacal light would glow out in two long tapering arrowheads extending from two opposite limbs.

Mars would be recognised instantly, for it glows now with its characteristic red hue far surpassing that of trans-atmospheric viewing.

Before long, a distinct disc would appear, and no doubt the long fall towards our goal would be filled to a great extent by examining this disc and noting the growing detail resolving as we drew nearer.

Almost at once the Polar Caps will become visible, as they are the planet's most conspicuous markings and it will probably become evident that one cap is much larger than the other, depending on whether it is winter or summer in that particular hemisphere.

As our orbit is most likely to be in the Plane of the Ecliptic the axial declination of Mars will be apparent. Approximately similar to the Earth's, it is 25° to the plane of its orbit. A slight fuzziness towards the limb will tend to obscure our vision and this, together with a glow, particularly on the sunrise limb, will indicate an atmosphere and probably a condensation of some constituent in it.

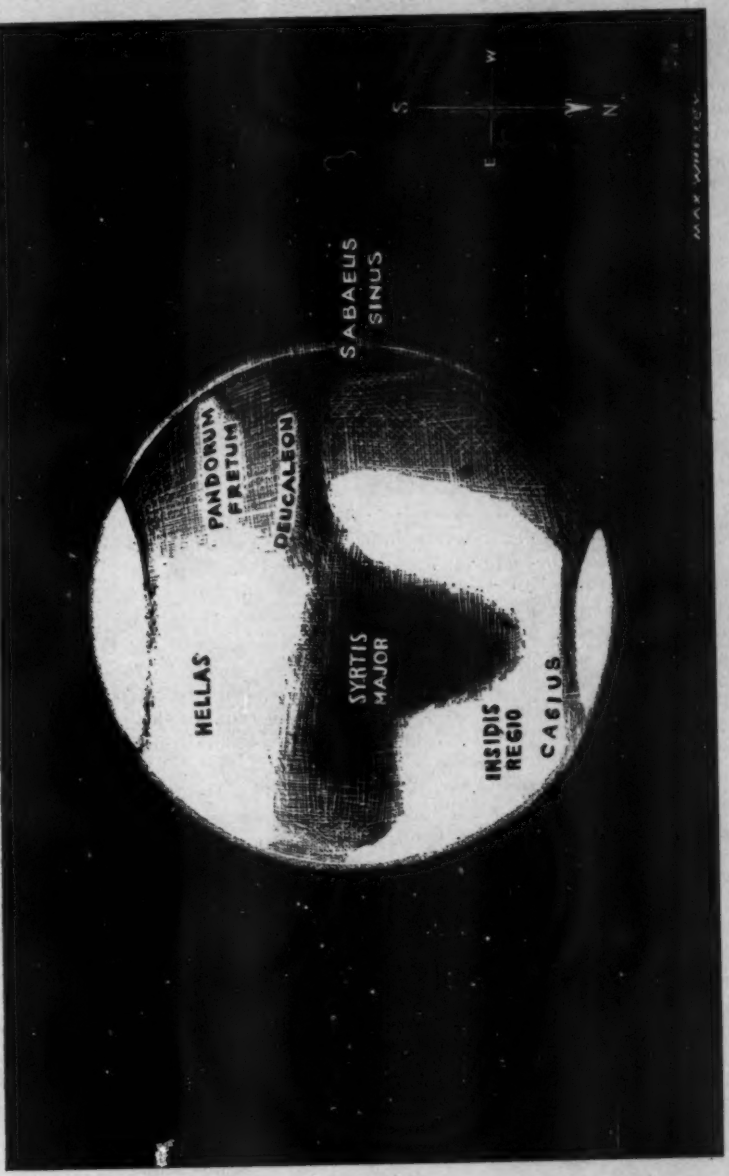
The surface markings will resolve from a uniform red to shades of reds, yellows, greens and browns, with admixtures of all of them. To quote Lowell—"It is a globe spread with blue-green patches on an orange background."

The greater percentage of the reds are to be found in the Northern Hemisphere, showing the vast extent of the deserts which cloak Mars. In fact these desert regions total about half of the whole of the area of the surface.

Apart from the Polar Caps, the greenish and green-blue regions are the most noticeable; occurring approximately in the Equatorial Regions they extend completely round the planet in a very irregular band.

As more and more detail resolved, such telescopic features as the smaller "oases" would become visible. As in the case of the Moon, the first observers misinterpreted these surface markings and made them analogous to those on the Earth—so the large greenish regions became "seas," and were given names like Mare Erythraeium, Mare Acidalium and Mare Sirenium.

Owing to the fact that a planetary body having large extents of water would exhibit solar reflection points, and as none of these has ever been seen on Mars, it seems certain that no large bodies of water exist there. Other evidence which will be mentioned later corroborates this.



Mars from about 50,000 miles.

The great desert-like wastes became known by unqualified names such as Hellas and Elysium. Smaller features were identified as gulfs, lakes, woods, straits and marshes. Examples of these are found, for instance, in Sabaeus Sinus, Solis Lacus, and Pandorum Fretum. It is noticeable that very few names of mountain ranges appear—the result of uninterrupted erosion. In geological structure Mars is more the counterpart of the Moon rather than the Earth, for Mars has a much smaller mass, its diameter being approximately 4,000 miles compared with 2,000 for the Moon and 8,000 for the Earth. According to the Laws of Thermodynamics, Mars must have cooled comparatively quickly, and its structure, thus becoming rigid, prevented mountain-forming agencies and isostasy, which both depend upon internal rock flows, from forming new heights and sharp contours, to replace those which had eroded. The levelling action of atmospheric erosion thus had full scope. So much so, that to-day it is impossible, according to Lowell, to detect *any* mountains on the terminator; this, he says, limits any raised land to less than 3,000 feet. However, it is extremely difficult to study such features, which must be obscured somewhat by the atmosphere.

It is fairly certain that there *are* regions raised a little above the general land surface, for when we examine carefully the particular Polar Cap which is diminishing we see isolated patches of white left in the melting regions, and an examination of records shows that these isolated patches occur regularly in the same place each year, thus indicating the existence of low hills which delay for a period the complete dispersion of the Polar Cap.

A case of this sort occurs at the Southern Cap. Regularly each year a detached portion of the Cap becomes visible around the beginning of the Martian June. (It has been given the name of "The Mountains of Mitchell.") Flagstaff observers seem to favour the opinion that, owing to the low density gradient of the Martian atmosphere (which we will discuss later), the snow is more likely to be resting on the slope of the hill than on the summit, as the water-carrying capacity of the atmosphere decreases much more quickly than on Earth, as altitude increases.

It is now fairly certain that the white deposit on the Poles is really snow, because the temperature at the Poles during mid-summer rises above the melting point of ice. On the other hand, for two reasons, it cannot be a very thick layer—probably only a few inches at the most. In the first place the heat received by Mars is only 40 per cent. of that received by the Earth and is, therefore, insufficient to melt a very thick deposit; while secondly, although tests of the most exhaustive nature have been made in order to find evidence of water vapour in the Martian atmosphere, the results have been negative. Spectrograms have been made when the velocity of the Earth relative to Mars has been at its greatest, and comparison spectra have been obtained from the Moon's surface at the same time, but the requisite absorption lines have not been found. Therefore the conclusion is that the total amount of water in the atmosphere must be very small.

There is very little indication that this deposit is carbon dioxide, as has been suggested by a number of authorities, because of the extent of the changes in temperature and the fact that the mid-summer temperatures at the Poles

rise above that of the vaporising temperature of solid CO_2 (— 80° C.). As it is, the Northern Cap never diminishes to below 200 miles in diameter.

Again, there is the evidence of condensation in the glow seen on the sunrise limb of the planet. CO_2 does not condense in globular liquid form but changes straight from the "dry ice" to the gaseous stage. Herschel bears the distinction of being the first to suggest the similarity between the seasonal changes of the Polar Caps of Mars and the changes of our own Polar Caps.

An examination of these Polar regions by the expedition would reveal further facts. If the ship arrived during the Northern Winter it would then be seen that the Northern Cap extended about half-way to the Equator, whilst the vanishing remnants of the Southern Cap would be observed, surprisingly enough, about 250 miles from the Geographical Pole. This happens consistently each Southern Summer. The Northern Cap does not, on the other hand, diminish to less than 200 miles in diameter. In the course of a Martian year, the maximum diameters attained by the Polar Caps are 3,700 miles for the Southern and 3,100 miles for the Northern. The reason for the greater diameter in the case of the Southern Cap and its complete disappearance, as against the minimum 200 miles diameter of the Northern Cap, is that greater extremes of temperature are experienced by the Southern Hemisphere.

Let us now examine the Deserts. These vast regions of varicoloured substances—possibly sand—covering half the planet, must present a very beautiful picture if the erosion of the ancient watercourses has remained undisturbed. It will be rivalled on Earth only by the Painted Desert of Arizona, which is an ancient sea bed where the stratified rocks and Petrified Forest combine in a fantastic pattern of colour.

The Martian desert will not be as hilly as are some of its Earthly counterparts, but the dark sky, blending from a light blue at the horizon to a deep black overhead, the cold stars and the small blue flaming Sun, would contrast in a striking way with the countless hues of the desert, hues ranging from yellow to deep red. Observers agree to a surprising extent on the tones and colours of these regions. W. H. Pickering at Harvard has studied these colours and conducted experiments to eliminate the psychological error of judgment of the eye. This is due mainly to the attempt to paint the surface of Mars with colours illuminated by artificial light, whilst viewing Mars through a telescope and seeing it illuminated by direct sunlight. He concluded that the desert areas are shades of very red granite or a tone between orange brick and dark red brick, a colour known as "Dragon's Blood." Lowell confirms this by stating that the deserts are a reddish ochre.

It is probable, however, that scattered among the "sandy" wastes and stratified beds are regions similar to the dry mud-deserts of Arabia, for owing to the thinness of the atmosphere, the winds must be light, allowing the arid ground to settle into a hard surface. In addition, it is also probable that extensive surface cracking has taken place in some areas.

The Green Belt of Mars

Assuming that our expedition has now approached the planet close enough to see finer details of its surface, much interest will be roused by the appearance of the Equatorial regions. It is roughly around these parallels that the

permanent darker colourings of Mars predominate, and it will readily be seen that as many variations of tone and colour exist in this belt as in the varicoloured desert areas.

To recapitulate, a glance at the names given to the more regular and permanent of these features will be sufficient to note their similarity to those of the dark areas of the Moon—indicating, as mentioned before, that much the same reasoning must have taken place—briefly, that the light-coloured areas must be land masses, and the dark-coloured regions—seas. In the same way the smaller dark-coloured markings were given names ending with "Lake," "Inlet" or "Bay," but it is extremely doubtful whether any water in any great quantities exists in free state in these regions to-day. There is, however, a distinct difference in the misnomenclature of the dark areas of the Moon, and that of the same areas of Mars. For whereas it is considered most unlikely that the regions of the Moon which the ancients considered as bodies of water, had ever been associated with water, it is practically certain that their Martian counterparts are, in fact, ancient sea beds. So perhaps in the case of Mars the naming is not so very far from the truth.

It is as certain, on the other hand, that no extensive bodies of water exist on Mars, for several reasons. One is the negative evidence from spectroscopic sources, and the other the total absence of a visible "solar reflection point" anywhere on the surface.

There is somewhat doubtful evidence that these dark areas are lower in general than the surrounding desert regions, though probably not more than 1,000 or 2,000 feet.* This is consistent with the proposal that they are the beds of ancient seas, and as such would be the last places on the planet—apart from the Poles—to retain moisture in its free state. In addition to this the depressed character of these regions, however small in degree, would result in the collection and deposition of most of the atmospheric moisture. This is further emphasised by studying the water-carrying capacity of the Martian atmosphere, which must fall off rapidly with height despite a density gradient 2·68 times less steep than that of the Earth, due to the smaller gravity. This is because the average temperature of the atmosphere is very low, and its density, even at the surface of the planet, is small compared with that of the Earth. Both these factors seriously reduce the height below which water vapour can exist. Below this level occur the mists and rare vapour clouds which obscure parts of the surface of Mars at times, and above it form the more frequent filmy clouds analogous, perhaps, to our cirrus and the rare mother of pearl and noctilucent clouds.

If we assume that Mars at one time had an abundant cloak of vegetation—and it is not unreasonable to do so—it would have vanished from the raised continents, as the water and oxygen wasted away, in step with the growing deserts. Finally, the last vegetal tracts would be sustained by the moist sea beds long after life had vanished completely from the surrounding tablelands.

The colours of these dark regions suggest that Mars may still be in this stage of planetary decay, and that there still exist some types of vegetation, most probably of a degenerate character.

* *Earth, Moon and Planets* (Whipple), p. 225.

The colour changes associated with these regions further suggest the probability of their being due to vegetal cycles, and although these changes are of a somewhat erratic nature, they can, in many cases, be predicted with a fair expectation of success. The anomalies of our own climate and "regular seasonal changes" will show that variations in an expected cycle of colour changes are not sufficient grounds to refute the theory. Other authorities have expressed belief that some of these colour changes are due to moisture mingling with certain salts in the soil, so causing a change in colour. Hygroscopic salts, too, may contribute to local changes. Arrhenius proposed the theory that the darkening of the "canals" is due to the combination of the moisture in the atmosphere with these salts, which, he maintains, are deposited in their depths.* It is fairly certain that some very transitory changes like the temporary darkening of portions of the desert regions are caused by the moistening of the iron oxide mixed with the sand, but due to rapid evaporation these changes are very short lived.

With regard to the main and fairly regular changes, their sequence has, for a long time, suggested similarities to our Earthly cycle of vegetable growth and decay, with the difference that on Earth the cycle takes place over a period approximately half as long as that of Mars. This is, of course, due to the relative orbital periods, that of Mars being 687 days. Another point which favours the idea of seasonal change is that the axial declinations of the two planets are almost identical; thus, the same angular effects of the Sun's rays must cause the procession of spring, summer, autumn and winter to be much the same as on Earth, taking into consideration, of course, the difference in position in relation to the Sun. Relatively unimportant discrepancies in effect will be caused, however, by the extreme eccentricity of the orbit of Mars. It is a well-known fact that the Southern Cap begins to shrink earlier and re-form sooner than the Northern, showing that the corresponding temperature changes of summer and winter are more extreme for the South.

As has already been mentioned, the idea of vegetation on Mars is by no means universal in acceptance. A great number of authorities maintain that conditions on Mars preclude any possibility of vegetal types, but, nevertheless, the amount of circumstantial evidence for some kind of vegetable life, however lowly, is very great. A comparison between the appearance of a portion of the Earth's surface overgrown with vegetation and seen from a height shows a startling resemblance to regions in the dark belt of Mars, especially when the region on Earth contains few trees and is mainly of the nature of Veldt, Prairie and Moorland. Parts of the Russian Steppes, too, bear some resemblance.

On the whole, the Maria remain blue-green and green for most of the Martian year, but for a short time in dead winter they change to various tones of brown and chocolate. For instance, in Mare Erythraeum the following changes were observed by Lowell in 1903. Towards the end of the Martian December it was blue-green, changing around the end of January to chocolate. This persisted until about the middle of February. This, in time and colour, seems to correspond with the earthly spring foliage. Lowell then noted that this

**The Destinies of the Stars* (Arrhenius) p. 218.

freshness remained until the beginning of the Martian summer when the predominant tone became blue-green. This also bears a striking resemblance to the earthly cycle.

In 1924 Antoniadi reported that in addition to the green to brown changes, greyish or blue areas turned either to brown, brown-lilac, or to carmine. At the same time, other areas of green and blue tones remained unchanged. Perhaps here we may have some analogy to our evergreen zones.

Other areas in the main belt seem to change erratically, without seasonal stimulus. These may be due to the previously mentioned combining of moisture and chemical salts. On the other hand, if we are to subscribe to the vegetation theory, it may be that in these areas the growth of vegetation is so finely balanced that the variation of the small amount of vapour in the atmosphere is sufficient to retard or stimulate it; much as a bed of plants in a shallow tray would wilt and wither as soon as regular watering ceased, to revive again almost immediately on a resumption of watering. In this way, the shallowness of the tray bears an analogy to the small depth of irrigated soil which must serve to support the plant life, if any, on Mars. Such a region is Solis Lacus.

In other regions, the usual brown stage in winter is followed by a further change to yellow.

The probable forms of possible plant life will be discussed later in the light of a discussion on atmospheric and temperature conditions.

The "Canals"

It seems certain, from the observational evidence of eminent astronomers belonging to both factions, that in addition to the permanent markings already described, there are, on the surface of Mars, more finely detailed markings.

These have been the cause of one of the greatest battles in astronomical history.

As this battle has already been related in broad outline, we will now discuss the cause. It will be remembered that there were two main schools of opinion, one led by Lowell on the side of an intelligent origin, and another led by Barnard and his associates in favour of a natural explanation.

Firstly, here is the Martian picture as Lowell and his followers visualise it. It must be emphasised that this is only one opinion and in no way represents the mind of the majority. In fact, it is probable that if a census of opinion were taken at present, it might well be that the majority is in favour of the natural explanation. However, the picture visualised by Lowell is a possibility which has led to fascinating speculation. If it *is* right, in part or in whole, this is what may confront our expedition as it approaches the planet.

A vast and intricate network of lines, graded in thickness, trace across desert and vegetal belt alike. The widest markings are about 100 miles across, with the rest grading down in size, until the finest defy the efforts of the eye to resolve them. There would be a distinct resemblance between their dis position on the planet and the venous system of a human body. This likeness, according to Lowell, would be strikingly apt. The large lines are the main arterial canals, collecting and delivering the meagre water—the very life-blood of the planet—from the Poles to the secondary canals, and so on to the

capillaries which strive to maintain life in the individual habitation centres.

The canals intersect at numerous dark spots which have been named "oases" or "groves," and which Lowell supposes might be the centres of the waning Martian civilisation. Some of these canals are double and travel with great evenness parallel with one another. They are mainly straight, but exceptions are gently curved and some are diffuse in outline. Others seem to suggest that use has been made of ancient river beds for sections of a particular canal's length.

Lowell observed that at the time when a Polar Cap commences to disperse, these canals seem to darken in a progressive manner from 78° N. Lat. to the Equator in about 52 days or at about 2·1 m.p.h.* This has been roughly checked by other observers† and, according to Lowell, is evidence of the flow of water.

It makes a tantalising picture, and I suppose the innate spirit of adventure in many of us urges us to accept it as factual. It must, however, be realised that all this is supposition and speculation, built on quite a fragile structure of fact. Mars is an extremely difficult object to observe, and years of intensive telescope work, with perhaps only half an hour of excellent seeing conditions a month, are needed to develop the peculiar sharpness of vision which characterises a planetary specialist of long standing. It is a major tragedy in the science of astronomy that in the column of air between the instrument and outer space, exist infinite variations in air density, and, as a result, in refractive index, even on the clearest of nights. And as these variations are changing character continually, disturbing things can happen to the disc of a planet under observation!

(It has been said that many an amateur astronomer has sworn off anything stronger than boiled water after viewing Jupiter through a telescope in an industrial town!)

Auto-suggestion is a powerful influence when both eye and instrument are at the limit of their resolution, under the above conditions. Pickering and others believe that this, plus the tendency of the mind to link a succession of dots or detailed markings into straight lines at a distance, explains much of the belief in straight canals.

In direct contrast to the possibilities offered to us by the "Intelligence Faction," Barnard, Trumpler, Antoniadi and their disciples paint a rather more sombre picture. Arrhenius presents their side of the case, and a little of his own, very lucidly, and states that the illusion of the "canals" is purely geological and their straightness is due to their origin as cracks or fissures. He bases his assertion on the rectilinear formations of such faults on Earth and takes for his example a map by Sederholm, the Finnish geologist, of the earthquake centres of Calabria and Sicily. The tremor lines are straight or gently curved and cross at points which are centres of collapse. Many of the lines are parallel. Thus, he says, the canals are dislocation grooves, and it is from these grooves that most of the water existent on the surface of Mars emerges. As this water, which will contain various hygroscopic salts, such

* *Destinies of the Stars*, p. 212.
† *Earth, Moon and Planets*, p. 225.

as the chlorides of sodium, calcium and magnesium, is evaporated, the salts are left behind at the bottom of the faults. And it is these salts, he maintains, which cause the progressive darkening of the so-called canals, by atmospheric water vapour, as has been mentioned previously. It would act in the manner of a liquid and flow into the portions of lowest altitude.

Some of the observers assert that there are no continuous lines—the markings are too detailed for that. Antoniadi, in his book *La Planeté Mars*, deals at some length with what he terms "the illusion of the canals" much on the same lines, and he, personally, doubts the existence of the "double lines," or "parallel canals."

It is possible, too, that some of the marks are those surrounding old, uneroded waterways.

It may be useful to end this section with a summary of opinions:—

Lowell and Douglas maintain that the markings are fine and straight, with some of them double; Pickering insists that they are curved, but admits the possibility of illusion; Trumpler is convinced that they are gently curved but very diffuse; while Barnard and Antoniadi are just as sure that the pattern is too complex to be straight *or* curved for any great distance, and in addition, Antoniadi disbelieves in the double effect. Schiaparelli, strangely enough, for it was he who, to a large extent, had started the argument by his choice of "canali" for the name of these markings, remained neutral. He did, however, keep an open mind on the subject.

One fact emerges from it all—our expedition will find *some* form of a complex pattern of markings which change in visibility throughout the year, and to some extent from year to year, for it has been noticed that some markings disappear for sometimes several years, and others vary in width from year to year.

There the case rests, pending further evidence, or until our hypothetical expedition becomes a fact.

The Martian Atmosphere

About the Martian atmosphere, however, we know a little more. We have already noted that unmistakable evidence of a thin atmosphere can be seen in the haziness on the limb of the planet, while the twilight and sunrise glow denotes condensation. The twilight glow has been seen very effectively when the planet has appeared to us in a slightly gibbous aspect, in which position, refraction in the atmosphere has caused a twilight zone of about 8° to be visible beyond the area of direct sunlight.

As we go closer, whitish clouds can be seen high up in this atmosphere, particularly around the melting Polar Cap.

The depth of the atmosphere has been estimated from comparison between the image of the planet in ultra-violet light and that observed in infra-red. The infra-red wavelengths, being longer than the violet, penetrate the haze, down to the planet's surface. The ultra-violet, on the other hand, gives an image of the atmospheric shell. The difference between the two images gives the height of the atmosphere. It appears to extend upwards about 50 to 60 miles.

Owing to the weaker gravity on Mars—0·38 of that of the Earth—equivalent columns of atmosphere on the Earth and Mars would contain very different amounts of gas—much less in the case of Mars. Therefore, even if the Martian atmosphere contained the same gases in the same proportions as does the Earth, there still would be much less oxygen per unit volume in the case of Mars.

A figure of approximately 2·5 lbs. per square inch at ground level has been estimated as the atmospheric pressure. It is apparent from this that a human being on Mars must wear a pressure suit in order to maintain a pressure round his body above that of the vapour pressure of water at his body temperature—an oxygen headpiece would *not* be enough.

Returning to the topic of clouds, it is observed that these whitish clouds mentioned above are transparent to infra-red and are therefore thought to consist of ice particles. They form and disperse in a matter of hours, mostly over the Polar regions, but are frequently seen over the warmer portions of the planet. It has been established by graded photographs in lights of increasing wavelengths, that under the level of these clouds and rising from each snow cap is a thin blanket of mist which is not apparent when observing Mars in normal sunlight. This veil gives the observer the illusion that the snow caps are more dense than they really are.

There are the other clouds which at times obscure large areas of the planet, and occur much lower down in the atmosphere. They are invisible to ultra-violet, but visible in infra-red. These persist much longer than the ice clouds, and are most likely composed of air-borne sand and iron oxide.

Although the atmosphere of Mars is transparent to infra-red light, a certain amount of absorption takes place in much the same way as on Earth. There is, in fact, three times more infra-red absorption on Mars than on Earth, showing that though there is much less atmosphere, what there is is three times more yellow than the Earth's. The extremely desiccated condition of the surface may account for this.

As to its composition we can only conjecture. We might reasonably assume that Mars started out with a similar atmosphere to that with which we ourselves started, as the chemical constituents of Mars are similar to the Earth's, but from then on we can only suggest what might have happened to it.

The escape velocity of the Earth is in the region of 7 miles per second, and as very few molecular motions exceed this figure at the normal temperature of the air we have probably kept within our gravitational grasp most of these initial constituents.

But not so with Mars.

The lighter gases such as hydrogen and helium must, by now, have almost completely vanished into space, as the escape value for Mars is only 3·1 miles per second. The escape must have been extremely gradual, but there the old saying about little drops of water must have become a fact.

In the terrestrial life cycle our oxygen is replaced by the plants which use up most of the carbon dioxide in the process. Thus they keep in time with the use of the oxygen by everyday oxidation, and the consequent appearance of the carbon dioxide as a product of this reaction. It is probable that this

also happened on Mars, until the slow oxidation of the surface rocks made an appreciable reduction in the oxygen content of the planet.

This oxidation is apparent on Earth. The "weathering" of rocks always has a reddening effect, especially if they contain any iron, as most of them do. A ubiquitous example we have in ordinary building bricks—only here the oxidation is accelerated and helped by heat.

It seems a definite probability that the flora of the planet died off at a speed which kept pace with the irreversible oxidation of the rocks, until to-day there is just enough vegetation to balance the present meagre oxygen content of the atmosphere. In other words, given the type of vegetation on Mars, we may be able to use the quantity of it as a measure of the oxygen content, in comparison with the Earth's.

Of the gases which used to make up the air of the planet it seems feasible to say that little but the heavier and more inert gases are left. Nitrogen is a possible example. On landing in this sparse atmosphere the expedition would experience thin keening winds in the desert regions, caused by the sudden changes of temperature. The nearness of the horizon will, no doubt, cause a feeling of strangeness, and the sight of two moons in the sky at once, one travelling in the opposite direction to the other, will require some visual conditioning. For Phobos circles the planet in 7 hours 39 minutes, whilst Deimos, with more like our own Moon's progress, takes 30 hours 18 minutes. It may seem peculiar to see Phobos rising in the west and setting in the east!

The ease with which members of the expedition trip and fall to the ground, using their normal earthly muscle impulses, will produce a rueful caution. Falls, however, will be soft, and as soon as sufficient control of muscular movement has been attained, it will probably produce, psychologically, a feeling of well-being. More than twice the normal load may be carried with ease, and in this way, any transportation of equipment will be greatly facilitated.

Although observations have been made on cloud movements, there is no apparent prevailing wind system, similar to those of Earth and Jupiter.

Surface Temperatures

As to actual temperatures, it is known by radiometric methods that the changes are extreme, owing to the thinness of the atmosphere. However, regarding exact values, it must be realised that these readings are tentative, and can only represent tendencies. Calculated values tend to be much lower as a whole.

The average temperature reading for the whole planet is about −25° C. (−13° F.), but the hottest temperature is as much as 30° C. (86° F.), whilst the lowest recorded is about −85° C. (−121° F.). As to the hottest temperatures, these are recorded on the green areas at noon, that is, around the Equator. As a contrast, the twilight temperatures of the same region are as low as −12° C. (10° F.).

Land surface plays a part in temperature just as it does on Earth. Temperatures in the Green Belt are on the average about 10° C. (18° F.) higher than for desert regions of the same latitude.

Moving to the Poles we find that although the temperature rises above the

melting point of ice in summer, in winter it sinks to around −70° C. (−94° F.). Taking the planet as a whole the temperature falls rapidly from noon onwards until at midnight it is much below zero—about −85° C. (−121° F.). This is maintained during the night and the same reading has been recorded on the white frost-covered strip which appears along the sunrise limb under the glow of vaporisation.

It is apparent from these values that the complete diurnal fluctuation is great—as much as 115° C. (207° F.). The reason for this is mainly due to the thinness of the atmosphere, which allows planetary heat to radiate away rapidly as soon as the heat source is obscured, so that at sunset, before the Sun has actually disappeared (which it would do with disconcerting suddenness), freezing temperatures are general, even in the Green Belt.

The lack of water vapour in the atmosphere causes the maximum radiation of the planet to take place at noon, when the greatest amount of heat is being received. On Earth the water vapour absorbs the heat waves, being of long wavelength, and delays the maximum radiation until the afternoon.

The pressure suits worn by the members of the expedition must be able to withstand these great fluctuations of temperature. It is probable, however, that by the time our expedition is launched, the suits will have already been designed to stand the rigours of outer space, in preparation for a breakdown along the orbit, so the problem may not arise.

Life Forms on Mars

We are now in a better position to discuss the possibilities of life on Mars, both plant and animal, but it must be emphasised that this aspect of a highly controversial subject is even more conjectural, though it provides highly interesting speculation.

It is probable that the expedition will have landed near some part of the Green Belt in order to settle this question of life—and others. We will first consider plant life.

It is obvious that whatever life, if any, which exists unprotected on the surface of Mars will be subject to rigorous conditions relative to our own. Firstly, extremely little water; secondly, extremes of heat and cold; thirdly, only 40 per cent. of the heat per unit of surface which we ourselves receive; and fourthly, the soil which still has life-supporting properties will most probably be in an exhausted condition with regard to growth compounds. In addition, there is the tenuous atmosphere to add to its tribulations. Quite naturally, comparisons with similar conditions on Earth are sought. Types such as Arctic mosses and lichens are at once suggested, or perhaps desert plants which are able to store water. Species of mountain cactus may here be a possibility. Still in comparison with the Earth we find that, in addition to mosses, coarse shrubbery survives high up on the Tundra and on high mountain sides when all else has disappeared. Here again we may have a similarity.

We may also approach the problem from an entirely different angle and try by logic to arrive at a probable plant form. Evolution appears to work by a species of natural selection, which is only another name for slow motion logic, so we may arrive somewhere near to the truth.

Our hypothetical plant must be able to exist on very little water, it must gather as much sunshine as it can, whilst it can, and then reduce its exposed surface to as small an area as possible to conserve its inner heat throughout the frigid night. It also must be able to exist in very poor soil.

The picture conjured by these conditions must vary from person to person. A suggestion of my own is this:—

A cabbage-like plant with thick, fleshy leaves and a moisture-storing organ deep inside its structure. It opens out to a large diameter as soon as the rays of sun are hot enough. As insect pollination has probably been long extinct, the inside colour of the leaves might merely be green. The whole plant is able to bend itself to a certain extent to keep its heart to the sun. Then, as the sun is sinking, the plant begins to close up until it is as near to a perfect sphere as is possible, which shape, together with its enormously tough insulating skin on the outside of the leaves, conserves its heat until the morning.

Seed dispersal is probably achieved by explosion, as wind agencies are no longer very powerful, and most species may be bisexual. Only those forms which, by long selection, have become symbiotic will probably have true sex.

Finally, each plant will have a vast root capillary system, in order to amplify its nourishment-gathering powers.

There you have it.

Whether it is somewhere near the truth or not it is impossible to say—yet.

After gazing around at the varied flora, if any, our expedition may set out in search of animal life. In this search it may be disappointed because of the lack of animal life *on the surface*. In all probability, if any exists, all unprotected animal life will be troglodític to some extent, feeding on the plants only in the heat of the day. Most will live in the deepest hollows of the old sea beds where the air is most plentiful. Evolution may have given them huge lungs in comparison with their bodies, with a totally different method of assimilating the oxygen. As sounds will carry very thinly on Mars, their auditory organs may have become more sensitive, possibly with large, trumpet-like projections for amplification of the sound waves. They must be able to exist with little water, perhaps storing it in the same way the camel does. Like the camel, some forms may have stores of fatty tissue in their bodies for purposes of survival.

The possibilities are endless, and become more intriguing when we turn to the prospect of intelligent life. This has been the moot point of a thousand heated discussions, and hence I tread with care.

There are two main fundamental possibilities. One is that because Mars cooled down quickly and became fixed in geological pattern, evolution had no time to produce a truly intelligent species before the slow death set in, and the surface starved. In this case, what forms did appear and develop remained lowly, and these we have discussed. On the other hand, evolution may have speeded up *because* of the rapidly changing conditions from luxuriance to desiccation; and this together with the probable effects of an increase in cosmic ray intensity as the atmosphere thinned, would produce a truly intelligent species.

This species, by necessity and the instinct of racial preservation, may have devised the measures already suggested by Lowell to prolong its life.

Given this race we have three further possibilities.

The first is that the race may have been overcome by the adversities of a dying planet and subsequently died out. The second is that members of the species may have adapted themselves *physiologically* to their changing environment and have developed into a form far removed from that which they possessed in the dawn of their development. For instance, their respiratory system, probably similar to our own in our early days, would be useless in the present atmosphere of Mars. It is almost certain that the pressure of this atmosphere is near the water vapour-pressure of an earthly warm-blooded creature with our average blood temperature of 98·6° F. It therefore follows that if evolution progressed on Mars in its early stages in the same order as on Earth, the lungs must now have altered basically. Another possible course is that the blood temperature has become lower. This would enable a being with a blood temperature of 77° F. to exist in one-twelfth of the atmospheric pressure of the Earth with earthly lungs. Similarly, at a temperature of 60° F. this critical pressure becomes one twenty-fourth.

However, a lower body temperature bespeaks of a lower metabolic rate and, under certain circumstances, may mean a lower intelligence.

Enlarged and sensitive auditory organs like those of our hypothetical Martian animals will probably adorn some position on its upper anatomical structure. Eyes, if any, being delicate, will be well protected. Possibly their telepathic powers have developed instead of physical auditory faculties.

The third trend of possibility is that the Martian race adapted their *environment* to suit their bodies. In this case, most likely, they gradually became troglodític themselves and their cities and habitations were constructed underground, where the temperature extremes were avoided. Air conditioning, using gases produced from natural minerals in the ground itself, may have provided the Martians with an agreeable atmosphere. Here they may have found deposits of water in underground pockets, and here, the natural air would be at its densest.

It has been asked many times, "Why is it, when the Martian race is supposed to be so intelligent, that *they* have made no attempt to conquer space, or signal to the inhabitants of other planets?" In the above we may have an answer. The fierce struggle for existence under the crust of Mars and the attempt to escape from the discomfort and desolation of the upper surface may have formed in their minds a kind of racial introspection, where all thoughts are turned to their new life in the comfort of their deep habitations, the "outside" becoming a legendary nether-world, visited only extremely infrequently. Probably it was just a few cranks of individuals who were bent on enduring discomfort for the sake of a bit of knowledge, bringing back strange tales of the powdered ruins of great cities, mouldering where the silted and dried up waterways joined.

Probably these few never even looked at the cold, black sky and its unwinking stars, except to shudder at its frigid aspect, and wonder how ever the race had been able to build these cities, cleave the waterways, and remain alive.

Then, perhaps, after a little more pottering among the ruins they once more headed their air-sealed vehicles towards the little-used air-locks on the

surface. And down in the light and warmth of the planet's interior showed to some of their mildly curious fellow beings the odd specimens they had brought back.

Conjecture all this may be, but it is all we can do at present.

Just think of yourself as one of that first party out there on Mars, suddenly striding across the icy sand with quick anticipation. Just think of yourself, clad in a bulky suit, the faint hiss of oxygen in your helmet, striding enormously on the red sand, towards a belt of green on the near horizon. Your companions are alongside, hastening towards the same splash of cool colour.

What is it that they and you will find? Probably something similar to that which has been described.

Perhaps not.

Data about Mars

Diameter	4216 miles; 6784 kilometers
Mass (fraction of Sun's mass)	$\frac{1}{3,093,500}$
Density	3·95
Astronomical symbol	♂
Albedo	0·15
Surface gravity (compared with earth)	0·38
Velocity of escape	3·1 miles/sec.
Mean distance from Sun	1·524 astro. units
Siderial period	$687^{D}·0$
Synodic period	$779^{D}·9$
Eccentricity of orbit	0·093
Inclination of orbit to ecliptic	1·9°
Orbital velocity	15·0 miles/sec.
Volume (Earth = 1·0)	0·15
Mass (Earth = 1·0)	0·11
Period of diurnal rotation	24·6 h
Maximum surface temperature	86° F. (radiometric value)
Number of satellites	2
(*a*) Phobos; diameter	Not more than 15 miles
(*b*) Deimos; diameter	Not more than 7½ miles

Data on Satellites of Mars

Phobos	
Mean distance from planet (in astronomical units)	0·000062725
Siderial period (days)	0·3189103
Eccentricity of orbit	0·017
Deimos	
Mean distance from planet (in astronomical units)	0·00015695
Siderial period (days)	1·2624406
Eccentricity of orbit	0·0031

References

Specialised Works	
La Planeté Mars	Antoniadi
Mars as an Abode of Life	Lowell
The Destinies of the Stars	Arrhenius

GENERAL WORKS

Earth, Moon and Planets	F. L. Whipple
General Astronomy	H. Spencer Jones
Astronomy	Skilling and Richardson
The Biology of Flight	Fitzpatrick and Stiles
The Origin of Species	Charles Darwin
Patterns of Life	Wells and Huxley

DISCUSSION

Mr. M. W. OVENDEN, F.R.A.S.: Mr. Wholey has given us a very interesting account of the surface features of Mars, and I am sure it will have brought many questions to your minds. I would like to open the discussion this evening by giving a little consideration to one point only—the much-debated question of the "canals" of Mars. I make no claim to be anything but a novice at Martian observing, but I think I may be able to give the observer's attitude to the question, an attitude seldom portrayed without bias in text-books.

I would emphasise that there is no doubt that at the limit of telescopic vision there is a mass of detailed markings—what is very much in doubt is whether these markings show the sharply defined, uniform, geometrically straight character of Lowell's canals, character on which his hypothesis of artificiality rests.

To a reader of astronomical books a first view of Mars through the telescope will be disappointing; he will see a few faint, hazy green-black markings, very unlike the detailed drawings he has seen—much more like the usual Martian photograph. If, however, some of the more prominent details are pointed out to him by an observer he will be able to see them—but only those details, not others. In other words, he will see Mars through the eyes of his mentor, and it will be some time before his drawings take on a character of their own; even then, they will bear a "family resemblance" to those of his mentor. The importance of this personal factor has been emphasised by F. J. Hargreaves in his presidential address to the B.A.A.[1] We cannot thus immediately apply the check of consistency, for any member of the Lowell group would tend to exhibit, by virtue of this effect, a superficial consistency with the others of the group.

The adverse effects of the atmosphere on telescopic definition prevent any satisfactory photographic check on Lowell's work, and further render any increase in telescopic aperture more or less unable to assist. In fact, except on very exceptional nights of fine "seeing," 18-in. aperture is probably the largest convenient size for planetary observing.

When we turn for a check to the observations of Lowell's contemporaries, we find ourselves in difficulties. We have Slipher and others under Lowell at Flagstaff persistently depicting canals of the Lowell type; equally experienced observers with similar equipment, such as Barnard at Yerkes and Mount Wilson, and most of the European observers, show no trace of fine, geometrical canals, but instead show all detail as more or less diffuse. The influence of mentors is obvious (and it may be pointed out that Schiaparelli, the "discoverer" of the canals, was Lowell's mentor). Modern observations show practically no "canalist" drawings, and there has been a tendency for drawings (even of the same observer) to become less and less like Lowell's.

With very few exceptions, experienced Martian observers do not now show the "canals" of Mars as fine, geometrical straight lines.

We have to consider three possibilities: (*a*) that Lowell and his associates saw better than anyone else (although canals were reported by Perrotin and Thollon at Nice). Some support is lent to this idea by the fine Martian photographs from Flagstaff showing exceptionally steady atmospheric conditions. However, the well-known observer, Professor W. H. Pickering, has observed frequently at Arizona and he states that[2] "I have *never* seen the planet with hard, well-defined lines as indicated in the (Lowell) drawing." (*b*) Lowell's canals were an optical illusion. This would explain why most observers have not seen the canals, and

indicates that increasing experience is the reason for the steady departure from Lowell-type drawings with later observers. Experiments by E. W. Maunder at Greenwich Hospital School[3] have clearly shown that the presence of a mass of detail indistinctly seen does give rise to the illusion of fine, straight "canals." (*c*) The possibility (suggested by Mr. Hargreaves) that the character of the canals was as Lowell depicted them in his day, but has now changed. Support is lent by the fact that many obviously broad markings (e.g. Nepenthes-Thoth and Cerberus) occupy the positions of Lowell "canals." This hypothesis does *not* explain the mass of observations by contemporaries of Lowell which do not show canals.

There the matter rests! It is not wise to be too dogmatic, or to "take sides" on the question. It is, however, wise to remember that great doubt exists as to the objective reality of canal-like markings on Mars, and any statements of widths in miles, etc., can be little else than meaningless. The general opinion of experienced observers is, I think, well summed-up by the present Astronomer Royal.[4] "Whilst it would be unwise to make too definite an assertion, the balance of probability seems to be in favour of the supposition that the canals are subjective."

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(1) *B.A.A. Journal*, 55, No. 1, p. 2, October, 1944.
(2) *B.A.A. Journal*, 32, No. 5, p. 165, March, 1922 (interesting discussion).
(3) Davidson, *From Atoms to Stars*, p. 86, 1944.
(4) H. Spencer-Jones, *General Astronomy*, p. 225, 1943.

PHOTOGRAPHING THE CANALS OF MARS

A recent paper* by Edison Pettit, of Mount Wilson Observatory, surveys attempts at recording photographically the Martian "canals," none of which has so far proved successful. He then examines the geometrical and physical aspects of photographing such fine detail with various emulsions, and comes to the conclusion that the limiting factor is the terrestrial atmosphere—given perfect optical conditions, a telescope of 30 in. aperture, or more, would be perfectly capable of photographing the canals of Mars. He then proposes that a large telescope be used with a cine-camera system, giving as high a frame-rate as is consistent with the necessary exposure time (which would be of the order of 1 sec. with 36 in. aperture, $\frac{1}{4}$ sec. with 60 in. and $\frac{1}{30}$ sec. with 100 in.). However, as he points out, it would be improvident to tie up a large telescope on such a programme when, during an apparition, possibly only a few minutes of the "super-seeing" conditions that are necessary actually occur. The problem is further limited in that the author believes that useful work can only be done when the apparent diameter of Mars is greater than 20″ of arc, which would not occur at all at an unfavourable apparition, and for only 80 days under most favourable disposition. He therefore suggests using a pilot telescope of smaller aperture (say of 20 in. for the 100 in.) and if approaching conditions are very good, the programme of the primary instrument can be interrupted while the latter is swung into position and the camera started. Such action requires efficient intercommunication and prompt execution, as the possible period may last only a few minutes and may not occur again during the whole apparition. Such a programme may be undertaken at Mount Wilson during the next favourable apparition (summer, 1954).

* *Pub. Ast. Soc. of Pacific* 59, pp. 125–29, June, 1947.

THE INTERPLANETARY PROJECT

By A. V. Cleaver

A paper read to the British Interplanetary Society in London on 11th October, 1947, this being the first meeting of the 1947–48 session

Introduction

The U.S. Rocket Society, in its official publication of May, 1947, congratulated the B.I.S. on its activities: "with the exception of excursions every so often into the unreality of the world they would like to re-make here on Earth. However, this is the natural outgrowth of frustrated intellectuals who dream of the conquest of worlds—and have to come back to the reality of financing experiments. The first rocket to the Moon will set them right!"

This comment is a little surprising, because the B.I.S. has given little appearance, outwardly at any rate, of having devoted much thought to the question of who will ultimately foot the bill for interplanetary research. Before the war, it is true, we issued a pamphlet which proclaimed, in capitals worthy of the Great Farnsworth himself, that: "THE MONEY SPENT ON A SINGLE DESTROYER WOULD MORE THAN FINANCE THE FIRST EXPEDITION TO THE MOON." It was not one of our predictions in which we can feel much pride, because (as some of us thought at the time) it revealed an optimism forgivable only on the grounds of enthusiasm. This present paper returns to the subject after an unwarranted neglect, because, after all, we none of us want our dream to remain as such—we want it to become reality. This will need hard cash and executive action, not merely technical and philosophical theorising; scientific experiments and engineering construction involve the expenditure—especially nowadays, as I will endeavour to show—of a tremendous outlay of man-hours of labour of all kinds, and pounds or dollars are merely a way of measuring this. (It should not be necessary to stress this, but if anyone feels that this discussion over-emphasises the sordid financial aspect, let him regard £P as merely a way of expressing $C \times P$ man-hours of effort.)

Such an outlay will not be forthcoming unless one sort or another of human interest is aroused, and surely it is one of the functions of a society such as ours to play its part, even if a small one, in exerting some influence in this direction. At the very least we cannot fail to be interested; it would be an untenable view to hold that there was an inevitability about Man's eventual conquest of space, and that the question of just who will accomplish it and with what immediate motives may, therefore, safely be left for time to reveal.

We have had lectures before this Society which discussed the broader aspects of the philosophy—the "Why?"—of space flight, such as Clarke's admirable talk introducing last year's session. We have also published many other papers discussing different technical aspects of the problem "How?" Now let us devote a little time to the more detailed economic, political and ethical sides to these questions of "How?" and "Why?"

Fiction

The only interplanetary voyages made by our species to date have been

flights of fancy. They are not to be despised on that account and it is interesting to see how their authors have imagined the circumstances capable of producing the first spaceship.

Usually the new development is born in the mind of a single inventive genius who retires to work out the complete solution in secret, in some lonely Welsh mountain fastness or the Arizona desert. After a few years, the unsuspecting world is astonished by a tale of astounding adventure and immense scientific achievement—success has come and space travel has arrived, but the narrative only rarely includes any account of how that event affected (or was affected by) the normal trend of human affairs.

Thus, H. G. Wells of his hero Cavor in *The First Men in the Moon*: "He told me of a workshed he had and of three assistants—originally jobbing carpenters—whom he had trained." Later we learn that: "All the intelligent work was done by Cavor," whose retreat was the Romney Marshes. ("Certainly if anyone wants solitude, the place is Lympne.") In this retreat, however, Cavor had all the facilities he needed: ". . . the sight of his equipment settled many doubts. It looked like business from cellar to attic—an amazing little place to find in an out-of-the-way village. The ground floor rooms contained benches and apparatus, the bakehouse and scullery boiler had developed into respectable furnaces, dynamos occupied the cellar, and there was a gasometer in the garden." Amazing, indeed!

All such pictures as this are painted from the viewpoint of the last century; the one actually quoted dates back to about that period, but it is more surprising and less excusable to find much the same ideas persisting in some quarters even to-day, and not always in the minds of writers of fiction alone. Until roughly the time of the first World War, it is true that many new and fundamental discoveries and inventions were made by private individuals, or small groups, working with quite slender resources.

A Scottish friend of mine, working in a very old-established shipbuilding and marine engineering firm on the Clyde, encountered some correspondence over 100 years old, relating to work done for Henry Bell in connection with his development of *The Comet*, the first successful steamship to ply in European waters. A bill for £50 for the boiler installation was rendered to Bell, who finally incurred a liability for the increased sum of £58 by delaying payment and losing the discount; apparently he had the unbusinesslike methods (or the shortage of money) traditionally associated with inventors. Again, it is recorded that the Wright Bros. spent only £4 on their first glider, and it is doubtful whether all their experiments leading up to the first successful powered machine cost them more than a few hundred pounds. When the wealthy Sir Hiram Maxim spent about £25,000, just prior to the turn of the century, on aeroplane experiments which were only partially successful, this was regarded as fantastically lavish expenditure.

A walk round the galleries of the Science Museum in South Kensington reveals why technical development was relatively so cheap in the old days, even after allowing for the fact that £1 then was equivalent to £3 or £4 now. Early machines required comparatively little in the way of precision manufacture or expensive materials, and the research needed in connection with

their design was of a nature which could be carried out with quite crude facilities. For that matter, during the same period most of the great fundamental scientific discoveries were also capable of being made with the aid of cheap apparatus which could often fairly be described as home-made. The position there was much the same as for the development of new inventions such as the early aeroplanes. These were structures of wood, wire and fabric which could easily be built by the practical handyman type of private experimenter for little cost in a shed in his backyard—as they very often were. Most of the old-established aircraft constructors can trace their history back to such origins.

Fact

Things are very different now, as an examination of any of the newer technical developments will readily show. Compare, for example, even the prototype Whittle gas turbines with the first steam engines of James Watt, or the V.2 rocket with the 1903 Wright biplane. The furthest example along this trend so far, of course, is provided by all the preliminary effort by so many workers which was needed before the first Fermi chain-reacting pile was able to operate in 1942.

Sometimes modern fiction writers take a step nearer reality and provide a wealthy backer or syndicate for their inventor; sometimes they go even further, and place the development in the experimental departments and laboratories of a big corporation. By taking the latter step, they recognise at least one further truth about modern technology, which is additional to (but obviously associated with) the vast increase in capital outlay involved. This is the fact that big developments now come, not from individuals, but from large teams of specialists, each making vitally necessary contributions to the overall achievement.

However, the lay public often has an erroneous idea of just how a big modern industrial concern operates when developing an important project on a large scale. It is frequently thought that such an organisation conceives a new idea, conducts experiments and research work and designs and develops the project at its own expense, finally selling the product either to the Government or some commercial user; in brief, that the whole process is one of private enterprise. Until fairly recent times, very often that was exactly what did happen; it still does occasionally, more so in the U.S.A. than here, because in the States individual capitalists and industrial firms alike have suffered less from the ravages of such things as surtax and excess profits tax. Nevertheless, even in the U.S.A., and certainly here or in any other country, the usual present situation is that the complete development of the larger technical projects is beyond the resources even of the giant industrial combine, let alone the individual financier.

What usually happens is this: the original idea may be (it very often is) conceived by a private firm or individual, who will probably do some preliminary work on it. Before long, however, the project reaches a stage where private enterprise requires (and I think deserves) some assistance in carrying it further. Application is therefore made to some Government agency for a development

contract; the firm may continue to pay part of the cost, but usually the taxpayer provides most of it, on the grounds that the project is one of national interest. Any special large facilities put up in connection with it, such as test beds or wind tunnels, are frequently State financed, either wholly or partly; such finance may be advanced as a loan repayable over a period of years, or it may be an outright grant made on certain terms. Again, once the project has reached this magnitude Government Research Establishments and other industrial concerns will increasingly be drawn into it for aid.

This system has certain advantages, though—from some aspects—it may seem cumbersome; there are political extremists who argue that the obvious solution is to nationalise all industry and research facilities, just as there are others who advance exactly the opposite view with equal heat, saying that if the State permitted larger profits to industry, then more of these things could be paid for privately. I do not now wish to take sides in these controversial matters; important as they are, they are mere side-issues to the point with which we are here concerned, which is this: the state of affairs just described has come about simply because modern technical development on the largest scale has outgrown the resources of relatively small private groups, even (in extreme cases) when these have the stature of the American giant corporation.

The total cost of design and development of any modern aircraft or aero-engine of large size, or of advanced or radically new type, now runs into many hundreds of thousands, or even several millions, of pounds sterling. The period covered by the work is several years and hundreds of specialised technical workers are engaged on it. All this, be it noted, for projects falling very far short of the magnitude of the interplanetary one; it will be instructive to examine a few published figures for the cost of other modern research and development projects.

The British Ministry of Supply spends £70,000,000 annually on all kinds of research. The Anglo-Australian rocket range will cost £3,000,000 in the first place, and a similar sum annually to maintain. This same figure is the one quoted for U.S.A.A.F. expenditure on guided missiles in 1948, though it is not the total American bill for such work—the U.S.N. and other agencies are also contributing. Peenemunde, which developed V.2 and other rockets, cost the Germans £20,000,000 at least. The huge American M.I.T. Radiation Laboratory employed 4,000 people, and this was probably much less than half the total number engaged on radar research in the U.S.A. alone during the war, when British and American efforts on this project were so closely co-ordinated.

Finally, as the best example of all, up to June 30, 1945, the Americans alone had spent £500,000,000 on the atomic bomb project, which employed 65,000 operating personnel on August 6, 1945, and which at its peak had also employed a further 125,000 construction workers. This organisation of the "Manhattan District" is the nearest approach to a model for the interplanetary project which man has so far achieved, for there is little room for doubt that the interplanetary project will be the biggest task of technical development ever envisaged.

There may just possibly be some whose reaction to all these astronomical figures is to say that they include vast sums which disappear down the sinks of apparent waste, delay, and inefficiency often associated with big firms and still bigger Government establishments. It is true that there seems to be an optimum size for an organisation to obtain the maximum tangible result from the labour of a man, and that this size is not a very large one. Huge overheads resulting from administrative charges, "paperwork" and systems, are an apparently inevitable parasitic growth in big groups, and can be kept down to reasonable proportions only by good planning and subdivision of responsibilities. However, the significant point for our discussion is that there are some tasks which can be attempted only by such large groups. It is as though we could use a small machine of 95 per cent. efficiency to do a small job, whereas for a larger one we have to employ a bigger machine of only 70 per cent. efficiency; such cases, of course, are not unknown in technology. It is also worth observing that, even if the figures quoted are halved to allow for alleged inefficiency, they still remain very large.

The last period at which a useful *practical* contribution to astronautics could be made by a small group dates back some 15 years to the time of the V.f.R. They (and other similar bodies) had a useful function to fulfil, which they discharged admirably and which was not subject to the objections connected with further advances. This was the early demonstration of certain radically new basic principles, on a small scale, for which small resources sufficed. Nowadays, however, anything which could be achieved by a rocket society or private experimenter with resources of only a few hundred, or even a few thousand pounds, would probably be merely misleading, as small-scale results often are. This opinion is, of course, advanced only in connection with practical experiments; where ideas are concerned—technical, philosophical or sociological—then individuals or small groups will always be able to make contributions which are the mainsprings of further progress. In fact, for these latter fields of activity there is much truth in the proverb recently quoted by the Pacific Rocket Society:—"A little poverty doth sharpen the wits and maketh the need to grow longer."

Conclusions

At some future date men will set up an agency charged with the fulfilment of the interplanetary project; in accordance with the modern predilection for euphonious nouns formed from initial letters, it will probably have some such title as "IPA." Perhaps one can visualise the events surrounding its formation more accurately than their actual date can be predicted. Perhaps it will be fifty years hence—I would guess that it is more likely to be slightly less than this, rather than much more, unless the crass stupidity of mankind in the meantime has imposed an indefinite postponement.

By the time our imaginary IPA is formed, high altitude rockets for meteorological, cosmic ray and other research, guided missiles, and aircraft propelled wholly or in part by rocket units, will all have attained a state of development vastly more advanced than that of to-day. Some of the high altitude research rockets will already have carried men several hundred, or even several thousand,

miles out into space. An unmanned rocket will very likely have been crashed on the surface of the moon as a scientific stunt; more usefully, perhaps a robot photographic projectile will have circled it to return to earth. Perhaps the first application of atomic energy to rocket propulsion will have been made, so that the stage will be set for the final act.

During all the period intervening between now and then, the idea of interplanetary travel will have become more and more accepted as something which is "bound to come"; of course, the progress in this direction during the last ten years has already been striking. Finally, some immediate reason will impel mankind to take the necessary practical step of forming IPA.

This organisation will probably lay down a programme something like this, in a series of stages each to be successfully performed before proceeding to the next, each having a value of its own but mainly intended to contribute to the ultimate end:—

1. The construction of high altitude research rockets capable of doubling or trebling the then-existing height record, carrying crews.
2. The construction of a manned ship to circle the moon and return without landing.
3. The construction of a ship to carry men to the moon, land and return.
4. The construction of ships capable of longer interplanetary voyages than (3), possibly using the moon as a refuelling station.

Probably there will be various competitive solutions to the problem of how the atomic rocket power plant should be designed; each of these might be allocated as a sub-project to different experimental establishments to develop. Thus there may be several alternative rockets designed and built to satisfy objective (1), the best of these being selected for further development through the succeeding stages. Some suggested solutions may be abandoned even before reaching the first stage, but only after considerable effort has been devoted to them.

Other aspects of the project—the hull design, the pressure cabin and air conditioning equipment, and a hundred vital chemical, metallurgical and nuclear problems—will also have been allocated to other establishments. Universities and industrial concerns will no doubt also play their very important parts, all activities being co-ordinated by the central IPA. The whole programme will employ thousands of workers in all grades and cost hundreds of millions of pounds.

The question remains: What "immediate reason" will impel mankind to embark on such a tremendous effort? To my mind the answer is clearly one of two alternatives. Only a very large State—what is now sometimes called a "Super State"—or a large association of States, could afford such a project. This implies more specifically the U.S.A., the U.S.S.R., possibly a more closely unified British Commonwealth, or some international organisation. A great new Asiatic power is, of course, another possibility, if it has time to develop before the IPA. situation arises, which is perhaps unlikely. Any of these

entities might undertake the interplanetary project for either of two reasons: let us consider the Utopian alternative first.

In a world free from the preoccupations, fears and compulsions arising from the threat of war, with all the wasteful expenditure of time and money on armaments which inevitably follows, a truer standard of values would arise. Projects having as their aim the gaining of new knowledge and experience, inspired by love of adventure and beauty and the spirit of curiosity, would increasingly absorb the attention of mankind. They would be a substitute for the stimulus of war with which man has so far found it impossible to dispense, a sublimation of the same basic instincts of aggressive and dynamic energy. Some such substitute would indeed be necessary if the species were not to stagnate; it is only among those individuals who already find their main interests in such directions that one finds a positive opposition to the idea of recurring wars. Such individuals may accept present wars as a regrettable and unavoidable necessity at the present stage in history, may take active part in them, but dislike them most violently all the same—and their dislike goes deeper than any resentment of personal danger and inconvenience. To them war is a barbaric relic and, as Wells once said: "An ugly spectacle of waste," a squandering of human resources in life and intellect and capacity for happiness.

There are, of course, very many available substitutes for militarism and nationalism as an outlet for Man's energies. All art and science, all social reforms, the defeat of poverty and disease throughout the planet—all fall within this broad category, but the interplanetary project could be one specific outlet, which is likely to capture Man's imagination by its inherently exciting nature. One can visualise, therefore, that the IPA might be an international organisation set up from these lofty motives and modelled rather along the lines of the American proposals for an International Atomic Energy Authority, or on U.N.E.S.C.O. The various separate establishments dealing with different branches of the subject might be situated in many countries all over the planet, the whole project being sponsored by U.N.O., or (better still) by a World Government.

The alternative to this Utopian ideal is a grim one; we began with a reference to Mr. Farnsworth, and may well end with one. The same effort might be called forth from a Super-State, or an alliance of States, prompted by decidedly less cultural motives. Instead, the motives might be the ancient ones of militarism and nationalism. No doubt it will sound far-fetched to many people now, but I find it very easy to believe in a future race to establish national bases on the Moon, a territory grabbing competition closely analogous to the one already so familiar on Earth. To all those who find this wildly improbable I can only put the questions: "How would an account of World War II, especially the atomic bomb phase, have seemed to you if you could have read it ten years ago, written exactly in the form in which you *now* know it happened? How much more fantastic do you think such an account would have appeared to the Victorians?"

It will not have escaped notice that most of the technical projects, for which figures of expenditure were quoted earlier, were ones mainly associated with

warlike aims. As regards the interplanetary project, perhaps we need not take too seriously the writings of Mr. Farnsworth in the U.S. Rocket Society publications, or those of Major Randolph in *Army Ordnance*, the journal of an American military society. However, they could easily be premature symptoms of an unhealthy trend which may later manifest itself on a larger scale in more influential quarters. The fact that the two writers quoted are both American could easily be coincidental and without significance, but the fact remains (as Major Randolph, in particular, has stressed) that any powerful nation would find many advantages in possessing bases on, especially, our satellite. If such bases could include facilities for manufacturing fuel and other products, as eventually they might, then there could be no better site from which to launch guided missiles against the Earth. As a still more futuristic extrapolation of this trend, one can envisage the possibility of Man carrying his wars with him into the rest of the solar system, if intelligent life is found there to oppose him.

The fantastic nature of these possibilities is exceeded only by their horror, futility and total lack of fundamental necessity. It is clearly incumbent upon all of us who associate ourselves with the interplanetary idea at this relatively very early stage, to ensure that mankind chooses the other, by no means impossible, alternative. In striving towards this end our efforts will often be needed in directions apparently unconnected with astronautics; the whole pattern of our lives and "the world we would like to remake here on Earth" is relevant. The phrase "all of us" is also to be taken literally; if we fail it will be futile to attempt to throw all the blame on to the "politicians," the "scientists," or any other vaguely defined class. We are all in this thing together, each with some microscopic grain of responsibility, and any attempt to evade that is the outcome of lazy and muddled thinking.

At least these are stimulating questions, a challenge to our minds and characters. For that reason alone, I, for one, would say that even if the trend is towards the second grim alternative of a militaristic development of the interplanetary project, then we must, nevertheless, see it through, striving to save all that we can for the cause of enlightenment at any given time. I do not subscribe to the view which characterises such things as atomic energy and rocket propulsion as "inhuman" and "unnatural," and wishes to stay their development at least until such time as Man has matured in the moral sense. In moral principle there is no difference between men killing one another by shooting arrows across a stream, and by flinging guided missiles from Moon to Earth. Our intelligence has developed our knowledge to the stage where we can indulge in the latter method, therefore it is entirely "natural" that we should build such devices, though if we do use them for that purpose it shows that our intelligence (or morality) has been unequal to a harder test.

However, one does not develop the mentality of a child by keeping him for ever in a nursery; he matures by attempting to handle adult situations for himself. Sometimes he fails, and that is often a tragedy, but it is not a mistake for him to have made the attempt. Man likewise must make his attempt; our current and future problems—including those of the interplanetary project—are the trials of adolescence.

DISCUSSION

Mr. L. J. CARTER (*Chairman*): I should like to congratulate Mr. Cleaver on his most excellent and stimulating paper. I now have very much pleasure in calling upon the other speakers on the platform.

Mr. L. R. SHEPHERD: There can be little doubt that the Interplanetary Project will cover a wider field of scientific and technological endeavour than any previous enterprise. It will involve a very large number of institutions and establishments and almost certainly more than one nation.

It can be said that preliminary work on the project is already in progress, since any long range rocket research is a step in the direction of the conquest of space. Thus, stripped of its militaristic purposes it can be said that the present work is aimed at the following developments:—

(*a*) The improvement of the performance of the chemical fuel rocket motor and its auxiliary equipment.

(*b*) The development of rocket structures, providing for storage of propellants in high mass ratio, particularly step construction.

(*c*) The design of devices, electronic and otherwise, for the control and guidance of long range rockets.

These developments will not suffice alone, to bring about the actual transportation of men and useful payloads to other planets, but we may expect a number of important limited objectives to be attained. We may expect that chemical fuel rockets will be developed with thrusts in the order of 1,000 tons, and that exhaust velocities will be pushed up to about 4 km/sec. Structural design should proceed to the point where robust multistep rockets can be built with effective mass ratios of the order of a hundred, and payloads of a hundred pounds, or lower mass ratios with higher payloads. Methods of controlling and stabilising rockets *in vacuo* should be established, and long range radio control perfected. These achievements should be accompanied by a number of developments of significance to the interplanetary project, viz:—

(*a*) The projection of useful payloads to heights of 1,000 miles or more.

(*b*) The construction of man-carrying rockets, capable of reaching great altitudes, with provision for safe return.

(*c*) The collection of essential data on conditions in space, and on the adaptability of human crews to the conditions of space flight.

(*d*) The development of methods of controlling and manoeuvring vessels in space.

It may even prove possible to put down a small payload on to the lunar surface, although this would be an event more spectacular than useful, since it is doubtful whether the payload would be great enough to include really useful telemetering equipment, nor could the payload be recovered. The projection of men and useful instruments to a height of a thousand miles, and their safe return, would be of far greater significance than the firing of a light shell on to the surface of the Moon.

Probably none of the above achievements will be undertaken as a specific preliminary to Interplanetary flight. It is far more likely that they will be incidental to the development of bigger and better methods of exterminating the human race. Nevertheless, we may be sure that the scientists and engineers responsible for these attainments will have one eye on the Moon, and will seize upon every opportunity to turn military expenditure to more laudable ends.

But what of the attainment of actual Interplanetary objectives—the first circumnavigation of the Moon by manned rockets, the first landing upon the lunar surface, and the safe return of the greatest explorers in the history of mankind? These great events cannot follow as mere incidentals to the improvement of guided missiles. If these events are to come about, then large funds will have to be allocated for the specific purpose of bringing them about. We must expect that the necessary expenditure will be astronomical in magnitude, and we may be sure

that no Government, or group of Governments, will be inclined to squander great sums of their taxpayers' money on a scheme that holds no great prospects of success. Of course, when some of the limited attainments, which we have mentioned, have been brought about, the whole project will begin to appear highly feasible. Nevertheless, something far more convincing must be put forward to attract the great funds required, and to persuade our Governments that the time has come when they can safely put forward the money. That "something" is undoubtedly the development of a propulsion unit with a performance far in excess of that of the chemical rocket. We may expect that it will be a nuclear powered unit. The question naturally arises as to whether such a device could be developed, without the allocation of a fair proportion of the funds needed for the Interplanetary Project as a whole. The answer is that it could be, for the design of such an engine would be a matter requiring the attention of a comparatively small number of scientists, engineers and technicians, while the full project would involve, as we shall attempt to show, perhaps 100,000 workers and scores of factories, research establishment, etc. As Mr. Cleaver has pointed out, expenditure of pounds and dollars ultimately boils down to expenditure of man-hours. Thus, we may expect that the development of a propulsion unit, occupying as it would do a relatively minute proportion of the man-hours required for the whole project, could be accomplished with a proportionally small expenditure, though technically it should prove the most formidable task.

These, then, are the essential preliminaries to the foundation of an Interplanetary Project:—

(*a*) Space navigation should be developed, using chemical fuel rockets, a little way outside Earth's atmosphere. In particular, safe methods of launching and landing large rockets should be perfected, and long range radio control methods should be developed to a state of complete reliability.

(*b*) A propulsion unit must be designed, having a performance satisfactory for Interplanetary purposes. This would probably be a nuclear powered rocket, developed in the course of the general programme for applying atomic energy. By a "satisfactory performance" we mean an exhaust velocity exceeding 10 km/sec. and a thrust in the order of a million kilograms; nothing less could be regarded as adequate for the propulsion of a manned rocket into deep space.

Numerous investigations other than these would, of course, be carried out during the preliminary stages, but we may assume that these would be covered by (*a*) and (*b*)—biological work on crew survival, for example, can be regarded as part of (*a*).

When the schemes, which we have outlined, have been brought to fruition, it may be confidently expected that Governments will be sufficiently impressed to make available large sums of money, and that large industrial concerns will be prepared to extend facilities for producing the necessary materials for an Interplanetary Project. Exploration has always been given a high priority in human affairs, and Interplanetary travel is exploration in a field infinitely richer than any which has previously been open to man.

In order to obtain a clear idea of the effort and expenditure involved in launching an Interplanetary expedition, it is necessary to consider in some detail the main factors involved. It would be necessary first of all to select a suitable site for the launching. This would need to be isolated from human habitation, but at the same time easily accessible, so that personnel and materials could be readily transported to the place. No doubt extensive roads and railways would have to be laid down and, possibly, many ships would have to be chartered. On the site it would be required to build a small township to house the workmen engaged upon the constructional work involved and the large staff of engineers and technicians directing operations and carrying out the more specialised duties. Small factories and workshops would, in all probability, be constructed within a few miles of the actual launching position, to carry out constructional work on the spot. Other plants

in distant, more highly populated areas, would also be involved in manufacturing the various materials, instruments and other equipment required. The actual space flight would probably be directed from a base station, perhaps thousands of miles from the actual take-off area. This base station would be equipped with a formidable collection of instruments and computors and possess a large operating staff. It would be linked up with powerful U.S.W. radio and radar stations at various points on the planet, and through these it would be responsible for the safe navigation of the spaceship during the greater part of its trajectory. It is extremely unlikely that such a delicate matter could be left to a navigator in the rocket, equipped with a slide rule and an "uncanny knowledge of the spaceways," though emergency operations could possibly be directed by the crew.

The first Interplanetary expedition would probably avoid the unknown hazards of a landing on the Moon, and would be content to circumnavigate the satellite in a fairly close orbit and return to the mother planet. The building and launching of the spaceship would probably be preceded by tests on small and full scale prototypes, which would be shot, unmanned, into space.

As for the spaceship itself, the sort of thing which we can visualise in the light of our present-day experience and knowledge is a structure weighing some thousands of tons, of which 80 to 90 per cent. would be made up of the stored propellant. In the rear would be the propulsion unit, very similar in principle to existing rocket motors, into which the propellant would be pumped, heated to a considerable temperature by a nuclear chain-reaction, and ejected through the nozzle to form the propulsive jet. The nuclear fuel, i.e. the material from which the nuclear energy was released, would probably be plutonium or uranium 233 (or even 235), while the propellant, which would constitute the bulk of the jet, would be some substance which evaporated to give a gas of light mean molecular weight—possibly ammonia. A fair proportion of the structural weight of the ship would be taken up by a massive radiation shield, protecting the crew from the lethal nuclear rays released in the engine: for the same reason the vessel would probably have a long slender shape, with the engine in the base, and the cabin space in the nose. The cabin would carry only the most essential instruments and equipment and supplies necessary for the comfort and safety of the crew. The main cost of the spaceship would be in the nuclear fuel and in the propellant material; the latter might consist to a great extent of deuterium, the separation of which is somewhat laborious and expensive (the present price in U.S.A. is $0·50 per gram, though it would of course be much cheaper when separated on a large scale). If the propellant were hydrogen or deuterium in the elementary form the storage of propellant and preparation for storage would be extremely costly, since the boiling points are so low. On the whole, however, we may expect that the spaceship would be less expensive than the ground facilities required for its operation, and the initial clearing and constructional items on the launching site. For this reason it might be economical to construct more than one vessel, and in particular, the building of prototypes would be fully justified. Of course, the base and launching site facilities could be used on many subsequent occasions, so that the average expenditure per expedition could be greatly reduced.

Some idea of the magnitude of an Interplanetary Project can be obtained from the above conjectural picture of events. The picture is one of hundreds of thousands of men, hundreds of factories and formidable sums of money, devoted entirely to the conquest of space. Mr. Cleaver has pointed out the fallacy of the backyard spaceship such as that visualised by Wells. In fairness to the writers of fantasy who have attempted to draw pictures of the great event, it must be said that they have not all treated the problem so lightly. Jules Verne, for example, in his famous novel, despite the shortcomings of his method of accomplishing the flight to the Moon, did at least visualise it as a great engineering project.

One might be inclined to ask what nation, or group of nations, would be capable of undertaking a project on such a scale. If these events were to come about within the next decade, the answer would be certain. Only America would be in an economic position strong enough to divert the necessary man-power and materials

to this project. However, the project is not likely to get under way within this period, and since in this fast changing world we cannot visualise the economic state of affairs 20 or 30 years from now, it would be rash to predict the identity of the fortunate ones. We may earnestly hope that it will be an international affair. At all events, Interplanetary flight will not be an enterprise to be undertaken by peoples struggling to recover from the upheavals of war and fighting for economic survival. Years of peaceful progress will be an almost essential preliminary to the project.

A few final remarks are worth while on the part to be played by societies such as the B.I.S., in the scheme of things. It may seem to many that a society supported by a yearly income of a few hundred pounds can have no serious place in the project. This, however, is not the case, for no matter what may be the total expense of the enterprise, there is certain to be a great deal which can be done at virtually zero cost. This is especially true of the mass of mathematical and theoretical work which must be done, and equally true of a great deal of the more fundamental experimental work. We have not far to look to find an example of this. The development of the atomic energy project cost the U.S. Government 2,500 megabucks ($2{\cdot}5 \times 10^9$), but the cost of the fundamental experiments, leading up to the great enterprise, was infinitesimal, as is evident from the fact that all these experiments were carried out in university laboratories. The aspirations of the B.I.S. may well be based upon the maxim that the pen is mightier than the test bed. Above all, it must be remembered that any scientific or engineering society is primarily a "mass-mind" responsible, through its publications, for the co-ordination of the ideas and results of individual workers and isolated research groups, and responsible, furthermore, for the stimulation of fresh lines of research and developments. Finally, any Interplanetary Society must be as much concerned with the impact of space flight upon society as it is with the technical aspects of its achievement.

Mr. R. A. SMITH: While I find myself largely in agreement with the previous speakers on the question of the size of the undertaking involved in a full-scale Interplanetary Project, and foresee that it will involve the necessity of co-ordinating a vast complex of associated enterprise, I also see the possibility of the actual event differing very considerably from the picture presented. From time to time methods have been proposed whereby the projected mass total can be reduced, and it is too early yet to decide the respective merits of these contending proposals. It has been suggested that Interplanetary flight proper will not commence from the surface of the Earth at all. I think that is correct if there should then be available other bases, either on the Moon or in the form of artificial satellites. It may even be that only the skeleton of the ship will be projected from Earth and at some appointed rendezvous in space it will pick up its fuel component.

Much will depend on the sequence of events leading up to the flight itself. Much will depend, finally, on the form that atomic drive will take. It may not be possible to use atomic fission in connection with the immense masses of material which will have to be ejected to obtain the thrust required, even if efflux velocities of 10 km/sec. are available in the main drive.

I do not think Mr. Cleaver has been fair about the cost, as much of that will be borne by developments completely different in purpose, but similar in technique.

When he speaks of the optimistic statements made by members of this Society in the past I felt that in belittling them he may not be doing the originators justice. We deliberately ran the risk of appearing optimistic, because we felt that it is the proper attitude for this Society to take. If, WE, the Interplanetary Society, are not optimistic about the successful accomplishment of this project, then we can hardly expect others to become infected with our non-existent enthusiasm.

After all, this Society was founded to *encourage* Interplanetary travel, although one might be excused the error of thinking, in the light of recent utterances, that the exact opposite was our purpose. We must acknowledge the difficulties, I agree, but there is no need to exaggerate them. I have heard a lot of negative talk about

"difficulties" but I await with some impatience the emergence of any practical or positive suggestion of action to achieve our ends.

Imperfect as it may have been, the old B.I.S. ship did arouse interest and comment. I have received letters from all over the world about it, even recently. I still maintain that because it was a positive suggestion it was worth more than all the "objective" wailing about the difficulties, no matter how scientifically expressed. It was at least a constructive suggestion as opposed to sterile comment. That suggestion served a useful purpose, even if it were no more than making clear what was not yet known, in determining the order of the problem which confronted us and in putting up for criticism a coherent conception of the problem as a whole.

Although there are now many people who are convinced that space flight is possible, there are few who have the foggiest idea of what a space-ship will look like. There are only conflicting ideas, and ill-considered preconceptions, which could be shown to be far less practical than, it is claimed, the B.I.S. ship was.

Certain fundamentals of the space-ship were then stated clearly for the first time, and so far as I am aware, little has emerged which has invalidated the primary conception. In fact, it is rather amusing at times to see how the more recent discoveries confirm the correctness of our first conceptions.

Even the coming of atomic energy has not altered the fact that the greatest possible economy must be effected in the return load and that everything which will not be needed on the return must be jettisoned as soon as it can be dispensed with. This means that the ship must be regarded as being largely expendable.

It is still true that the initial mass at projection will be of the order of 1,000 tons, and that the thrust requirement at take-off will require the operation of multiple units in parallel. It is still true that the step principle must be employed if there is to be any hope of realising the "mass ratio" required with any feasible reaction. It is still true to state that the most economical ascent will be vertical to begin with, and that rates of initial acceleration should not be too high, and although Mr. Shepherd's picture did not show this, it is still true that most of the equipment used at the launching site will be blown to smithereens, even if the launch IS successful. What is more important is the re-discovery of the fact that fuel density is a significant factor, and may exclude the use of certain otherwise promising fuels.

The science-fiction concept of an airship-like streamlined body, garnished with a decorative array of wings, fins and portholes, and mysteriously sustained with its major axis in a horizontal plane by repulsor rays, is still way off the beam. The point made by the B.I.S. for the first time was that the vast majority of the mass of the ship would be fuel tankage, and the carrying space an insignificant fraction, and owing to the great mass of the ship, the point loads sustained at the point of support must be considered and provided for, both in flight and while awaiting projection.

There are practical rocket experimenters who now realise that the regeneratively cooled motor cannot hope to realise exhaust velocities much in excess of 3·5 km/sec., even when developed to the limit of perfection, and that if velocities are required exceeding that figure some form of uncooled motor must be used.

I see no good reason to change the opinion that the launch should take place vertically, from a site at high altitude and preferably from a body of water. Water is more easily replaced than are the more static forms of scenery.

The theory that air resistance is much easier avoided than overcome will find its echo in the heart of most modern aerodynamicists.

It is not necessary to start from the bottom of the atmosphere and it would be very foolish to attempt it. There are sites available, accessible to the required degree, where artificial lakes could be constructed, at such an altitude that more than half of the total mass of the air is below them. This means that when the ship does reach sonic, at restrained acceleration, the density will be so low that the total loss to air drag will represent a minute fraction of the total expenditure of energy.

There are many such sites, both inside and outside the British Empire, but so far as I know, none in Australia.

I still hold the view that the Interplanetary Project proper will start with a landing on the Moon. There will be much to be done before that becomes possible, and so far as I am aware no member of the Technical Committee of this Society was so dim as to be unaware of that. We have always taken it for granted that at some stage, when motors become sufficiently reliable, there will be an ascent by a man-carrying rocket to a modest height, which will be succeeded by ascent to progressively greater heights until space itself is reached: then the technique of atmospheric re-entry will be developed from progressively daring excursions into space. Methods of changing altitude and direction will be developed into a complete technique of guidance and control *in vacuo* and finally a series of flights round the Moon will be made to investigate landing conditions more thoroughly. At any stage of this series, where there is any uncertainty of the outcome, it would be obviously sensible to replace the human pilot by a machine, part automatic and partly telecontrolled by signals from base.

This phase might take 10, 20 or 50 years, according to the intensity of effort put into it. Such a programme might, if it became necessary, be compressed into five years, but I do not expect that to happen. The rate of development of the motor and the ancillary equipment would largely control the progress. Much will depend on whether it is part of a concerted programme designed to build up to a lunar landing, or whether the information needed is brought to light incidentally as a by-product of rocket research for entirely different purposes. Under the latter circumstances the completion of this phase might even take hundreds of years.

That, I contend, is where this Society comes in. By drawing attention to the possibilities of space flight, and stating the requirements of a practical method of approach, we can exert pressure to accelerate events. I think this Society could become a powerful factor in the rapid achievement of our ends, but *only if it follows the right policy*. I think it could become very influential if it engages in constructive suggestion. If, on the other hand, it confines itself to an attempted duplication of the functions of existing establishments, it will become redundant, languish and die.

I disagree profoundly with the suggestion that there is no practical work we can do. If one is completely lacking in creative ability but wishes to become an "authority" in a given subject it is quite usual to set about it by reading and watching what other people are doing and by hashing the facts up into a "survey," rigidly sticking to the book, quoting only from other "authorities" who themselves quote "authorities" and so on *ad nauseam*. In order that such mental tape-worms should live, however, someone has to do something real. This requires original thinking, and some people are incapable of it. Generally, those who *do* start the ball rolling, do so with comparatively primitive equipment, sometimes no more than a typewriter or calculating machine. I will give some examples.

It was foreseen, years ago, that radio valves of the normal pattern would have to be superseded by other methods of generating high frequencies at high wattage, owing to the technical limitations of the thermionic valve. Well before the final limits of the valve had been reached, some far-sighted workers had anticipated events and were working on fundamentally different methods of achieving the same purpose. The Magnetron, Klystron and so forth were evolved, and showed that what could only be achieved with great effort by the thermionic valve could be surpassed by a factor of ten to the second power, almost without effort.

In the field of aeronautics, it was stated years ago that the propeller-driven winged plane might never attain sonic speed in level flight, and was severely limited both in speed and level of operation. The helicopter, athodyd, ramjet, jet and rocket were other answers, hopelessly outclassed at first, and for a time abandoned, due to technical impediment.

Suddenly the technical impediments were overcome, and now the performance of the finest normal aircraft is made to look rather pathetic. The internal combustion turbine, again, has boosted output to incredible levels.

In every field the orthodox has had to give way finally to some neglected or overlooked alternative. Those who could clearly see the limitations of the orthodox, and refused to accept them as final, worked on, often under official discouragement at first, and almost always without the excellent facilities available at national establishments. Finally they got results which could not be denied, and the "orthodox" suddenly acclaimed that which they had previously refused to acknowledge.

Just now the liquid fuelled, regeneratively cooled motor is the orthodox, but it is quite clear to us that it cannot fill the bill. We know that such a motor, no matter how perfect, cannot be expected to produce efflux velocities much in excess of, say, 3·5 km/sec., and that is inadequate. I hope that this Society will be instrumental in fostering some development which will completely revolutionise the whole outlook. For that reason, if for no other, I hope we do not *try* to duplicate the work of the national establishments, but try to supplement it.

If one of our members gets an idea which is new, and requires assistance to develop it, by mathematical or other theoretical analysis, or if he requires to be put in touch with people who could undertake development work, that is a matter for this Society. We may be bombarded with crazy ideas, but we can sort the wheat from the chaff, and I feel confident that in the end the trouble will prove worth while.

Official establishments cannot afford to play with dubious possibilities, they have to show results. Once an idea has been brought to the stage where it is developable they will be prepared to consider it. We could perform a useful function by acting unofficially.

Some of the alternatives which may repay consideration and have been previously mentioned in this Society are worth recalling. They are:—

(1) Eroding expendable motors.

(2) Pulse motors, with a short period of high energy working followed by a period of recovery, and possibly fuel injection.

(3) Non-adiabatic expansion by successive heatings and expansions in a long duct.

(4) Molecular dissociation of a hydrogen working fluid in an arc, with subsequent re-combination in an expansion duct.

(5) Other secondary reactions (separate heating and working fluid cycles).

(6) Non-oxidising reactions (substitution of fluorine for O).

(7) Chokeless motors (external combustion).

(8) Tandem combustion.

(9) Step rockets.

These suggestions are confined to the propulsion field alone and there are other matters of landing, projection, atmospheric braking, orbital manoeuvre, air conditioning, heat insulation and temperature control, directional control *in vacuo*, observation, navigation and communication.

All these things suggest to me possibilities of small scale practical experimental work which is most definitely not beyond the resources of this Society and its friends, and because they are problems which must be solved before the Interplanetary Project could become a reality, they are matters in which this Society can legitimately interest itself.

Before leaving this subject to Mr. Clarke, however, there is one observation I would like to make.

If Mr. Cleaver's picture is correct and the project is one needing the co-operation of people geographically dispersed, there must be, as he suggested, some controlling body. Where I differ from him is that I do not see the necessity for *creating* such a body because, in my view, it already exists. It is *this Society*. Our charter is unique. We are the only body in the world legally equipped to achieve this purpose. By the time it becomes a reality we should be better technically equipped than any other body in the world to do the job.

We now have members in every major country of the world, and in almost every research body touching on our problem. The qualification and influence of our Society steadily increases and I see no reason why that should not continue. Some of those who have not yet seen fit to join our ranks may be very pleased to do so later on. I hope they make up their minds in time.

If we choose to fulfil a secondary role of reporting progress made elsewhere, there may be need for the organisation described, but not if we conduct our affairs intelligently. We are the first, and only, body devoted to this subject now surviving. The majority of people in this room tonight will be alive when the first landing takes place. It is up to us, as a body, and as individuals, to see that our foresight is put to good account. It will be our fault if men, and organisations, not yet born, should be called to complete our purpose for us.

I do not think they will.

Mr. A. C. CLARKE: Mr. Cleaver has shown—and I do not think that there can be any serious disagreement with his conclusions—that the crossing of space is so enormous a project that it could not be undertaken in its entirety even by a giant industrial corporation, perhaps not even by a single country. I would like to develop this theme further and to show that this state of affairs may, in fact, be somewhat fortunate.

During the next generation all the major problems of astronautics will be solved, either wholly or in principle. But in most cases the engineering and scientific organisations which solve them will not be at all interested in space flight. They will be concerned with the development of aeronautics, atomic engineering or electronics: often they will be quite unaware of the wider applications of their discoveries. Consequently, although the experiments leading up to the first space-ship may cost a thousand million pounds—and must, indeed, have cost the greater part of this already—those experiments will be carried out in the normal course of technical development. Mr. Cleaver's "IPA"—which I prefer to call "Interplanetary"—need not initiate them except in special cases.

Thirty years from now the general level of scientific and technical knowledge should be so high that the design of a space-ship will be largely a matter of applying known principles—in some cases, of using equipment already to hand. Government departments and great industrial combines will have spent astronomical sums in developing, for their own purposes, the techniques which will make the space-ship possible: but the bill which "Interplanetary" will have to foot will be incomparably smaller. At a guess, if research proceeds at the present rate, and *if* the results of that research are made freely available, the cost of the first space-ship in terms of direct construction and research may be as little as £20,000,000. (Or 100 mega-bucks, to borrow the atomic scientists' convenient unit.) This is only a few times the cost of a very large prototype airliner even to-day.

The rising tide of technical knowledge will make space-travel *possible* in the closing decades of this century, but it will need some more definite impulse or driving force to ensure that it actually occurs then and not at some much later time. The role of bodies such as the B.I.S. in providing this impulse is obvious.

It is also very instructive to see if there are any lines of development which may, in the near future, make the achievement of space flight technically imperative. (It may already be politically imperative, but that is a different story!) Elsewhere I have tried to show that certain fundamental problems in radio communication will only be solved completely when we can build orbital "repeater" or relay stations in space. For example, television transmitters can only provide a reliable service out to the horizon and thus have a range of 50 miles or less, whereas three low-powered stations out in space could "floodlight" the entire world with television programmes and many other types of service which are now impossible. The situation is already so serious that airborne radio transmitters are being built in the United States, while attempts are even being made to use the Moon itself as a passive reflector of radio waves.

As soon as it becomes technically feasible we may therefore expect the great

broadcasting and communication companies to be vitally interested in space flight, since it will make possible the scrapping of thousands of ground stations and millions of miles of cables. The atomic energy corporations will also support astronautics: already there has been half-serious talk in informed circles of using rockets to dispose of the embarrassingly plentiful and extremely dangerous radio-active by-products from the atomic piles. Moreover, it seems probable that in the not-too-distant future nuclear research may enter fields which make it desirable—to say the least—that further investigations be conducted in free space as far away as possible from the Earth, or indeed any other matter.

There are even more spectacular possibilities which we cannot foresee to-day, but which will certainly arise in due course. I will merely suggest one—which I hope no one will take too seriously—as an example of what may happen.

All our lives we are fighting against the Earth's intense gravitational field, and there will be a great saving of bodily energy on the Moon. This may open up whole new fields in medicine, and may make it possible to cure, or at least to alleviate, many diseases, particularly those of the heart. It is by no means fantastic to imagine that cardiac sufferers doomed to an early death upon the Earth could live useful and happy lives on the Moon.

Even if this particular suggestion is wholly incorrect, we may be sure that astronautics, like all new sciences, will have other vitally important consequences some of which should be predictable in advance.

Such practical arguments for space flight will accumulate during the next generation, and perhaps by 1960 it may become feasible to set up a research organisation with a permanent planning staff to go into the problem of space-ship design in full engineering detail. "Interplanetary," as I have christened it, would at first operate on quite a small budget. For some years its main work would be the collecting of technical information and the preparation of plans and calculations. We may, I think, hope that the present Societies will assist materially with this object, and may also provide many of the technicians concerned.

The case of the Royal Aeronautical Society has been mentioned before, but it will do no harm to recall that this body, which now contains all the leading figures in British aviation, began nearly fifty years before the Wright Brothers first flew, as a small group of enthusiasts with far less public support or sympathy than that which we are already able to enlist.

I hope that, as befits its objects, "Interplanetary" will not be a merely national organisation. We in this country must do our utmost to sponsor full co-operation with serious astronautical societies throughout the world, and particularly in the United States. There is a tremendous opportunity before us, on both sides of the Atlantic, if we make our plans wisely. If we can achieve world recognition as the leaders of thought in this new field, if we can prove by our publications and our activities that our ideas are technically sound, then when the time comes we will play a major—perhaps *the* major—part in the conquest of space.

It matters little whether the first space-ship costs ten or a hundred million pounds. If it is clear that we have both the knowledge and the vision—and each is useless without the other—then the world will come to us when it needs our help.

We should not, therefore, allow ourselves to be overwhelmed by the immensity of the task, and hence to feel that we can play no important role in the future. The present interest in rockets and space flight is almost wholly due to the patient work of a handful of enthusiasts, and our activities may determine to a large extent the date at which space travel comes about. Nor is it, I think, too much to hope that we may play our part in seeing that astronautics becomes an instrument of good rather than of evil for the human race.

Mr. L. J. CARTER then threw the discussion open to the meeting, inviting the four earlier speakers to reply as they saw fit to any points as they arose. The lively and interesting discussion which ensued lasted for over an hour, and it is regretted that space considerations forbid our printing more than the following brief summary.

Several speakers reiterated the view that Interplanetary exploration had a most important significance as a future potential substitute for war, in providing an outlet for Man's energies. Mr. Clarke assured the meeting that he agreed wholeheartedly with this opinion, as did the whole B.I.S. Council. He would continue to strive for this ideal, but thought it was important not to spoil the case by premature emphasis, before the mass of mankind were ready to appreciate the point.

Mr. ALEXANDER HUNT said he came from the film industry and was currently planning a production which placed the achievement of Interplanetary travel some 500 years hence. He was sorry to take such a pessimistic view of the date, and gave as his reason the view that an atomic war, which would decimate the world's population, seemed inevitable in the interim. Much as he sympathised with the ideals of other speakers, after looking at the present situation he found it impossible to avoid that conclusion; perhaps after such a war the scientists might have the opportunity of organising a society in which such laudable aims as the Interplanetary Project might become possible of achievement—and from the right motives, too.

Mr. R. W. PARISH found it incredible that one nation could ever hope to gain the Moon as its sole property, to use as a war base. The first ship to land there would have much too small a payload to carry any equipment for establishing a base, and once one nation had got there surely others would be in a position to follow very soon afterwards.

Mr. CLEAVER agreed with these points in essence, but thought the speed of technical progress, following an initial achievement, must not be overlooked. The first flight of the Wright biplane could have taken place *within the wingspan* of the present B.36 or Brabazon I. Also, competition between nations to establish rival bases could conceivably act as a spur to such "progress."

A speaker asked whether the B.I.S. should try to develop as a learned society or as a popular body. Did it want to speed the crossing of space by scientific contributions, or to engage in propaganda on such matters as were being discussed that night?

Mr. CLEAVER thought it should do both things; its primary function was the technical one, but that was not incompatible with the other object.

Mr. GILLINGS welcomed the increased success and prestige which had attended the post-war reconstitution of the B.I.S., following which there had been a general raising of the technical level of the Society. However, he also hoped the popular membership would not be neglected, and heartily agreed with another speaker, Mr. J. BARCLAY-BARR of the *Sunday Dispatch*, who said that the journalistic profession were willing and anxious to help with the task of popularising the subject in all its many aspects.

Mr. H. C. CARTER, who said he spoke with great feeling as an artiste and historian, and not as a technical man of any sort, emphasised the widespread appeal of the Interplanetary idea. Space flight would be not merely a great scientific achievement, but a broadening of Man's horizons with tremendous sociological and artistic implications. He pleaded that, in consequence, the B.I.S. should never become a purely technical body.

Mr. L. J. CARTER (*Chairman*) said it was the policy of the Council to promote the growth of a well-balanced society, which would neglect no aspects of the subject.

Mr. H. E. ROSS supported Mr. Smith's view that the B.I.S. could conceivably develop into the authority finally responsible for organising the Interplanetary Project, itself charged with the duty of spending whatever sums were finally found to be necessary for practical work on experiment and construction. He thought the Society might find it possible to gain this position by contributing vital ideas on new principles of motor design, etc., which might not necessarily be brought forth even from, for example, the lavish scale of American activities.

Mr. R. A. SMITH added that the B.I.S. might eventually be strengthened by the incorporation in its membership of all leading workers in the rocket field, foreign as well as British. Already the B.I.S. had many overseas members and this trend might easily develop, resulting in a society with an international, rather than purely British character; he quoted the R.Ae.S. as an example of the kind of powerful body he envisaged.

Mr. CLEAVER pointed out that the R.Ae.S., and all other similar societies, organised lectures, conferences, examinations and exhibitions. It sometimes engaged in what might be called aviation propaganda, and it put out many technical publications, but it did not build aircraft, conduct practical research or organise pioneering flights, and it was therefore no precedent for the sort of development suggested by Mr. Smith.

Miss W. E. S. TURNER asked whether the B.I.S. was already co-operating with similar societies abroad; in particular, was anything known of Russian activities?

Mr. L. J. CARTER replied that correspondence and exchange of publications with American societies was already organised; B.I.S. publications were sent to Russian academic institutions as to those in other countries. No doubt the Russians were working on rocket problems just as was every other major country, but it seemed impossible to discover anything about their activities.

Mr. J. HUMPHRIES agreed that the Russians were almost certainly doing quite a lot; he believed they had captured most of the German B.M.W. staff at the end of the war, and occasionally references appeared in the *Journal of the Academy of Sciences of the U.S.S.R.* Such papers, however, were invariably theoretical and revealed very little. Mr. Humphries then proceeded to make several technical points. He challenged an opinion expressed by Mr. Smith, to the effect that future rocket motors for space-ships, giving very high exhaust velocities and working at extreme temperatures, might be of the uncooled type with eroding nozzles. He also asked why Mr. Shepherd had mentioned the possible use of deuterium or ammonia as a working fluid for nuclear rockets, in view of the fact that ordinary hydrogen gave a much lower molecular weight.

Mr. L. R. SHEPHERD replied that the attraction of either substance was the higher density, giving smaller tank volumes and also a reduction in mass of fissile matter required, and hence cost. Deuterium had also the virtue of a much reduced tendency to capture neutrons; for the same reason, "heavy" ammonia, rather than the common sort, would be considered. After allowing for dissociation effects, the molecular weight of the ammonia products was much reduced.

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ABSTRACTS

Physics of Rockets

(By H. S. Siefert, M. W. Mills and M. Summerfield, *American J. of Physics*, Vol. 15, 1947, illus., tabs., refs.)

This series of articles is intended to give the non-specialist an all-round picture of rocket propulsion from both theoretical and practical aspects. The authors are all well known in the rocket world and have chosen their material skilfully and presented it in a most competent and readable manner. All those interested in rockets, whether experts in the field or not, will benefit by reading these articles.

(1) *General Theory and Solid-propellant Rockets*

The first part (January–February, No. 1, pp. 1–21) is devoted to a simplified theoretical review of the principles of the rocket motor. All of the standard thermodynamic material is presented, i.e. the equations for adiabatic flow, flow through nozzles and the calculation of thrust. The second part on solid-propellant rockets discusses the application and manner of operation of both restricted and unrestricted burning types. The theory of solid-propellant operation is dealt with at some length, with special reference to restricted burning.

(2) *Liquid-propellant Rockets*

The desirable properties of liquid propellants are enumerated (March–April, No. 2, pp. 121–140) and with these in mind, various combinations are analysed. Under the heading "*Fundamentals of Liquid-propellant Rocket Design*" various aspects of motor design are considered, such as the effect of application, time of stay of propellants in the chamber, propellant injection, combustion initiation and heat transfer. The application to assisted take-off, super-performance and main propulsion of aircraft, and to missile and sounding rockets is also briefly covered.

(3) *Dynamics of Long Range Rockets and Rockets Utilizing Nuclear Energy*

This section (May–June, No. 3, pp. 255–272) is based largely on Malina and Summerfield's paper *The Problem of Escape from the Earth by Rocket* and Ackeret's paper *Zur Theorie der Raketen* (*J. B.I.S.*, March, 1947, Vol. 6, No. 4, pp. 116–123). In the second part the authors suggest various ways in which nuclear energy might be applied to rockets and comment on them.

Rockets

(By Victor Maurice. *Revue de l'Aluminium*, 1947, Vol. 24, pp. 69–74; from *Chemical Abstracts*, 10th Sept., 1947, Vol. 41, No. 17, col. 5700.)

The mechanical, physical, and chemical principles of the development of rocket construction in France, America and England, but particularly in Germany, are discussed at length and German types discussed in detail. The choice of the fuel is determined by the following considerations: it must have a high heat of combustion; rapid, almost instantaneous ignition; low molecular

weight of end-products; high density; automatic starting; safety in storage, transport and manipulation; and easy manufacture from constituents in abundance in times of war. A list of propellant combinations, together with theoretical and practical specific impulses, is given. The use and manufacture of T-stoff (80 per cent. hydrogen peroxide) is covered. The use of rockets for exploration of the ionosphere is briefly discussed.

Rocket Power Plants based on T-Substance (Hydrogen Peroxide)

(By Hellmuth Walter, National Advisory Committee for Aeronautics, Technical Memorandum, No. 1170, 1947, 20 pp.; from *Chemical Abstracts*, 10th Sept., 1947, Vol. 41, No. 17, col. 5701.)

This is a review of German investigations in the use of hydrogen peroxide as a source of oxygen in engines for the propulsion of underwater craft, projectiles, and aircraft. While possessing only a relatively low proportion of available oxygen for such purposes, the high heat of decomposition of hydrogen peroxide offsets this disadvantage. A graph shows the relation between concentration, heat content, and decomposition temperature. There is a close interdependence between the concentration of hydrogen peroxide and the temperature of the steam resulting from the decomposition; this suggests a system for the generation of constant-temperature steam. Decomposition of hydrogen peroxide occurs preferably with an aqueous solution of sodium or calcium permanganate (dens. = 1·5) atomised with the hydrogen peroxide into the decomposition chamber; or with catalytic stones of manganese dioxide, cement, and sand, which fill the decomposition chamber and against which the hydrogen peroxide is sprayed. With the liquid catalyst, 1 kg. of hydrogen peroxide per second per litre of decomposition chamber volume can be decomposed. As fuel for use with hydrogen peroxide, hydrocarbons, and a mixture of hydrazine hydrate and methyl alcohol are briefly discussed; graphs of adiabatic drops and temperatures versus concentrations and mixture ratios are given for these, as well as for the system hydrocarbon—mixture of 90 per cent. of 98 per cent. nitric acid and 10 per cent. sulphuric acid. Also discussed are questions of the specific gravity, cold resistance, storage and transportation requirements, safety hazards, and availability in Germany of hydrogen peroxide. A rather detailed discussion of rocket power plants using hydrogen peroxide is included, with drawings and photographs.

Solid and Liquid Propellants

(By W. H. Wheeler, H. Whittaker, and H. H. M. Pike, *J. Inst. Fuel*, 20 (1947), pp. 137–156, 159; Abst. partially from *Chemical Abstracts*, Vol. 41 (1947), col. 5307 (August 20). See also preliminary abstract in B.I.S. *Bulletin*, Vol. 2, No. 4, p. 78, 1947.)

Propellants are commonly used in cartridges, gun charges, and for rockets. The characteristic property of all self-contained or monopropellants is that they contain both combustible and oxidant in sufficiently intimate association to ensure rapid combination without the aid of atmospheric oxygen, with evolution

of heat and the generation of a considerable volume of gaseous products. The reaction which occurs when a solid propellant (such as smokeless powder) burns, always takes place on the surface of the charge; this is the characteristic difference from liquid propellants. With liquid propellants, relatively large combustion chambers to operate at a pressure of the order of 300 lbs/in.^{2} are required. The general nature of solid propellants and their manufacture is discussed. These are generally modified cordites.

Liquid propellants are classed as monopropellants or bipropellants, although the latter may consist of more than two liquids. The only established monopropellant is concentrated hydrogen peroxide (80 to 85 per cent.) decomposed either by a concentrated solution of calcium or sodium permanganate, or by a solid catalyst. This was used by the Germans in a glider rocket bomb, for launching the V.1, and for driving the fuel-pump system on the V.2. Methyl nitrate has also been considered, usually with methyl alcohol, but this mixture is explosive. Nitromethane shows most promise. Details of the manufacture of hydrogen peroxide are given.

Methods of evaluation of propellants are discussed. Self-igniting propellants start to react in the liquid phase as soon as the two liquids mix; non-self-igniting bipropellants may have to be evaporated before reaction starts; this requires a separate source of hot gases for an appreciable time, which may be supplied by an auxiliary charge of solid propellant. Sample calculations are given for the composition and temperature of the gaseous products and the calculation of the thrust from a nozzle. Application and design problems are discussed with respect to the combustion chamber and fuel delivery.

Although the authors relegate the bipropellant system, which is of extreme importance, to the background, this paper is of great interest and should be read by all members with a technical interest in rockets.

The Problem of Escape from the Earth by Rocket

(By F. J. Malina and M. Summerfield, *J. Aero. Sci.*, Vol. 14 (1947), pp. 471–480 (August), illus., refs.)

The problem of imparting to a given payload the necessary velocity to escape from the earth is re-examined in the light of recently released information on war-time rockets. The fundamental equations of motion of a rocket in outward radial flight are derived and the influence of each of the following design parameters is examined: c, the effective jet velocity; ζ, the ratio of propellant mass to initial mass; t_p, the time of powered flight; μ, the ratio of initial mass to maximum cross-sectional area; and C_d, the drag coefficient based on the same cross-sectional area.

The exhaust velocities attainable under standard conditions with rocket propellants range between 6,200 ft/sec. for nitric acid–aniline, and 10,200 ft/sec. for oxygen–hydrogen, the former being representative of dense propellants and the latter of light propellants. On the basis of the design characteristics of the V.2 rocket, it is believed that the maximum practical value of ζ that may be realised is about 0·85. Therefore, it is concluded that single-step rockets utilising propellants that develop their energy by chemical reaction

cannot escape from the earth. Escape may be accomplished by single-step rockets, however, if nuclear sources of energy can be used to heat gases of low molecular weight in order to provide much higher exhaust velocities.

The analysis is extended to calculate the velocity achieved by a multiple-step rocket. The overall mass of the rocket and the maximum velocity of the last step are related to the number of steps and to the ratio of the masses of successive steps. It is shown that the necessary velocity can be obtained with any of the rocket propellants available by proper choice of the number of steps. Various examples of multiple-step rockets capable of projecting instrumental pay loads away from the earth are presented.

NACA Reveals New Results of Supersonic Research Program

(By R. Hotz, *Aviation Week*, 7th July, 1947, Vol. 47, No. 1, pp. 18–21, illus.)

NACA's 1948 budget of $43,449,000 (previous year, $30,713,000) will be chiefly spent on supersonic research. During the past year various wing plan forms, sweepback and airfoil types have been tested—general results are given. Research has been conducted by three methods—wind tunnels; rocket powered, remotely controlled free flight scale models, and wing flow tests, in which models are mounted at the point of fastest air flow on P.51 wings. In the coming year, flight tests of full-scale piloted research aircraft are also to be used.

Standards of Human Comfort

(By M. Hottinger. Published in *Schweizerische Bauzeitung* (Switzerland), Vol. 65, Nos. 8 and 9, 22nd February, 1947, and 1st March, 1947. 11 pp., 15 illus. Long abstract given in *The Engineers' Digest*, Vol. 8, No. 10, October, 1947.)

This is an interesting and useful article giving much information on the desirable standards of heat, humidity and fresh air for human well-being under various conditions (e.g. when sleeping, working, etc.).

The Kew Radio Sonde

(By E. G. Dymond, *Proc. Phys. Soc.*, Vol. 59 (1947), pp. 645–666 (July), illus., refs.)

The British radio sonde is a system for telemetering indications of pressure, temperature and humidity from a free balloon to the ground. It is used on a large scale for routine observations of the upper air for meteorological forecasting. It works on the principle of a varying inductance changing the note of an audio-frequency oscillator, which modulates the radio transmitter. The design of air-borne instrument, ground-receiving apparatus and calibrating plant is described. An account is given of the performance of the radio sonde, and of the errors to which it is subject in actual operation. The probable errors are in the neighbourhood of $\pm$ 5 mb. and $\pm$ 0·4° C. for pressure and temperature over the atmospheric range up to 22 km. height, and $\pm$ 10 per cent. relative humidity down to temperatures of $-$ 20° C., below which the hygrometer element becomes unreliable or inoperative. The reliability is high, over 95 per cent. of the soundings being successful.

Flight Control of Rockets

(By G. White, *Aero Digest*, May, 1947, Vol. 54, No. 5, pp. 50–51, 142–143, illus.)

This article discusses the requirements of control systems with special reference to V.2 take-off problems and method of turning rocket into correct flight path. The effect of control error and the advantages of inner control over radar control are also dealt with.

Electronics for Cosmic-Ray Experiments

(By B. Howland, C. A. Schroeder, and J. D. Shipman, Jun., *Rev. Sci. Insts.*, Vol. 18 (1947), pp. 551–556 (8), illus.)

A method is described for detecting coincidences between the discharges of Geiger counters. The basic circuit uses diodes as coincidence tubes. The output from a diode circuit is the same polarity pulse as the inputs, hence the output from one coincidence circuit can be used to generate more complex coincidences. An example is given of a typical counter-tube experiment utilising the diode scheme. A formula is developed for the ratio of output for total and partial coincidence in terms of the pulse width and circuit parameters; in a practical case with a pulse width of 1μ-second a fourfold to threefold output ratio of 40 is obtained. Mention is also made of a combination diode-pentode coincidence circuit. The work was done at the Rocket Sonde Section of the Naval Research Laboratory, Washington.

Other Papers Noted

Two Notes on the Theory of Rocket Motion. A. J. Ishlinsky. Comtes Rendus (Doklady), Vol. 53, No. 7, 1946, pp. 595–596.

On the Theory of Rocket Propulsion. D. E. Okhotsimsky. Applied Mathematics and Mechanics (Academy of Sciences of the U.S.S.R.), Vol. 10, 1946, pp. 251–272. In Russian, with English summary.

Nuclear Energy for Aircraft Propulsion. G. M. Giannini. Air University Quarterly Review, Spring, 1947, Vol. 1, No. 1, pp. 43–51.

La Chemie des Rockets. Dr. L. Pessuche. La Nature, 1st April, 1947, No. 3133, pp. 123–124, illustrated.

Guide-beam Control Technique for V.2 Rockets. G. Hausz. Tele-Tech., March, 1947, Vol. 6, pp. 76–80. Basic principles and engineering details of radio equipment permitting accuracy within tens of yards at 100-mile ranges.

Upper Atmosphere Research, Report No. 1, mentioned in Zwicky's article "Artificial Meteors" in *Ordnance*, July–August, 1947. Report issued by Naval Research Laboratory.

Explosion and Combustion Processes in Gases. By W. Jost, published by McGraw Hill, £1 17s. 6d. A standard work recently translated into English. Available on order from most booksellers.

Acknowledgment

The Librarian begs to acknowledge with thanks, receipt of *The Electronic Theory of Valency* (Sedgwick), kindly donated by Mr. G. V. E. Thompson.

REVIEWS

Symposium on Materials for Gas Turbines

(A.S.T.M., 1916, Race Street, Phil.3, Pa., U.S.A. 200 pp., illus., tabs., refs. Price $3.00.)

This book contains eight papers on the high-temperature properties of materials, especially high-temperature alloys, together with discussions. Most of the information contained has not previously been published. The following three papers will be of especial interest to practising rocket engineers.

(1) "Heat-resisting Metals for Gas Turbine Parts." Cross and Simmons.

(2) "High-temperature Alloys Developed for Aircraft Turbosuperchargers and Gas Turbines." Freeman, Reynolds and White.

(3) "Chromium-base Alloys." Parke and Bens.

The Cross and Simmons paper is of particular interest as it offers an abbreviated presentation of the more important data contained in the many detailed reports issued by O.S.R.D. Results of short-time tension, stress-rupture and creep tests are given for materials ranging from modified 18/8 chromium-nickel steels to practically iron-free cobalt-chromium and cobalt-chromium-nickel alloys with addition of molybdenum, titanium, columbium, etc. Temperatures range from 1000° F. to 2000° F.

The Freeman, Reynolds and White paper deals in particular with the development of alloys for rotor and blade service in aircraft gas turbines, for working temperatures from 1200° F. to 2000° F. This paper is complementary to the one by Cross and Simmons and between them they provide data for similar types of alloys over the complete temperature range.

Parke and Bens give the methods of preparing chromium-base alloys and present certain of their physical properties. Those portions of 13 binary and 9 ternary systems of chromium containing more than 50 per cent. chromium were explored in a preliminary manner. Only the chromium-iron-molybdenum and chromium-iron-tungsten systems were studied in detail as in rupture tests at 1600° F. they showed the highest strengths with measurable ductility.

In all of the papers the composition, heat treatment and test results are tabulated and where possible graphically presented. Although many useful properties such as density, thermal expansion, impact resistance, hardness, tensile strength, yield strength, elongation, reduction of area, and stress-rupture results are given, it is unfortunate that the thermal conductivity, of prime importance in rocket combustion chamber design, is given only for pure chromium.

J. H.

Mathematical Theory of Rocket Flight

(By Dr. J. Barkley Rosser, Dr. R. R. Newton and Dr. G. L. Gross. McGraw-Hill, New York. 1947. Pp. 276. $3.50.)

This is essentially a monograph, prepared by a group of American scientists, covering the entire field of study of the motion of fin-stabilised and spin-stabilised rockets which was conducted at the Allegany Ballistics Laboratory during the war. It is published with the blessing of the American Office of

Scientific Research and Development, and its erudition is unimpeachable.

Every possible effect influencing the motion of a rocket in the atmosphere, during and after burning, is considered. No difficulty has been shirked, and whilst, as a consequence, the authors are bold in their hope that the treatment may be suitable even for those "with little scientific training," the aspiring or trained ballistician with no fear of mathematics will find much to learn. Each chapter is covered by simple physical explanations which will help the serious student; and the very comprehensive numerical tables of the unwieldy definite integrals, which occur in the trajectory calculations, would by themselves make the book of great importance.

It is very pleasing to find this subject dealt with rigorously and systematically, with a real sense of proportion where approximations are concerned; the problems of control by jets and toppling at launch are treated in a particularly satisfying form. However, a chapter on the assessment of aerodynamic characteristics of projectiles would have been a useful addition. The problem of motion under variable gravity is not included, and the treatment of near-vertical ascents would surely not be amenable—in general—to the approach suggested. For this investigates the motion during burning by formulating corrections (assumed small) to the equations of motion if the gravitational deceleration in the direction of flight is neglected.

But the underlying philosophy of well-proven methods is there: it requires little effort to apply it to less orthodox studies. T. R. F. N.

The Biology of Flight

(By Frederick L. Fitzpatrick and Karl A. Stiles. Published by George Allen & Unwin, Ltd., 40, Museum Street, London, W.C.1. Pp. 162, illus. 55. Price 8s. 6d. net.)

This is a book which deals in general terms with the evolution of flight, the effects of varying types of conditions on the body during modern flying, and a chapter on air travel and disease control.

It has been written primarily for air cadets and air crews, who naturally wonder why so many pleasant and unpleasant conditions may be encountered during all conditions of flying. It is a well-informed text-book, explaining the physiological basis of high-speed flight to non-medical personnel. Most of the conditions arising from altitude effects, pressure, temperature, acceleration, air-sickness and fatigue are dealt with. The authors give a most interesting non-technical explanation of these conditions—conditions which are certainly going to increase as faster planes are produced. No mention is made of supersonic flight, but this is undoubtedly because this is still in its embryo stage, and research is now going on to combat the unknown but probable effects of this new and interesting field. A. H.

Wilco-Wiggin Thermometal

(Published by Henry Wiggin & Co., Ltd., Wiggin Street, Birmingham.)

This little publication on bi-metals has been planned to assist designers of thermostatic devices to choose the materials, forms and sizes most suited to their purposes. L. J. C.

Performance and Longitudinal Stability of Jet-propelled Aircraft, with Special Consideration for Flying Airplane Models

(By P. Bielkowicz, Alma Book Co., Ltd., 52, Halton House, 20–23, Holborn, London, E.C.1. 79 pp. 8s.)

Mr. Bielkowicz is a Fellow of the B.I.S. who will be remembered by our readers as the author of an excellent series of articles on rocket propulsion, which appeared in *Aircraft Engineering* during 1946 and the early part of 1947.

The latter part of the title explains the real purpose of his present small book. It contains much interesting data on the small ramjet motors which are beginning to be used in America for propelling model planes and can be recommended to anyone interested in the fascinating hobby of model aircraft.

A. V. C.

Theory and Testing of Jet Propulsion Motors and Rockets

(By S. Fonberg. 5s.)

The Astral Aero Model Co. of Leeds has republished this American attempt to cover, in only 45 pages, the large field described in its title.

Unfortunately, many of the statements and formulae given in the pamphlet are very misleading, and in some cases quite incorrect. For example, it is suggested that the thrust of a rocket is given by:—

$$F = \left(\frac{2v - u_1}{2}\right) \times \text{Mass Flow per sec.}$$

where v and u_1 are the exhaust and flight velocities respectively, instead of by the correct expression: $v \times$ Mass Flow per sec. Also, an obscure argument is developed which appears to prove that the propulsive efficiency of a ramjet is always 100 per cent.!

This work is *not* recommended.

A. V. C.

NOTES AND NEWS

"Challenge of the Spaceship"

We were very interested to learn that this excellent paper, delivered to the Society by Mr. Clarke on 5th October, 1946, has now been reproduced throughout Czechoslovakia in a technical magazine.

The anthology, *British Thought*, 1946, which was published in America last year and which also contains a full reproduction of the paper, is now available to members on publication in this country by Nicholas Kaye, Ltd., 1, Trebeck Street, W.1, under the title of *Current British Thought, No.* 1 (21s.).

Visits to Hampstead Observatory

During the period from October, 1946, to March, 1947, many members were able to take advantage of the opportunity of visiting Hampstead Observatory and examining both astronomical and meteorological instruments. Unfortunately, the prolonged bad weather made it impossible for many members to take full advantage of the facilities and make actual observations themselves.

We are very pleased to announce that, by courtesy of Hampstead Scientific Society, these facilities will again be open to members and their friends.

Intending visitors should write to M. W. Ovenden, F.R.A.S., 22, Coppetts Road, Muswell Hill, N.10, for further information, enclosing a stamped addressed envelope for reply.

Compounded Annual Subscriptions

The Council has approved the following scale whereby members may compound their annual subscriptions and obtain Life Membership.

Age limits	Membership	Fellowship
	£	£
20–25	25	35
26–30	23	32
31–35	21	30
36–40	18	26
41–50	16	22
51–	14	18

Additional information may be obtained from the Secretary if desired.

National Physical Laboratory

A further visit to the National Physical Laboratory at Teddington has been arranged for 10th April, 1948, at 10 a.m. Members who would like to join the small party on this date, should write to the Deputy Technical Director, G. V. E. Thompson, 31, Brooklands Gardens, Gidea Park, Romford, Essex, for further information, enclosing a stamped addressed envelope for reply.

Last year the visit afforded an excellent opportunity for inspecting a number of machines used for testing the hardness, elasticity and other mechanical properties of materials (e.g. for use in gas turbine construction). Several wind-tunnels of both open and closed types were later examined, and the visit concluded with inspection of transformers, generators and other apparatus in the high-tension laboratory.

WANTED.—*Rockets Through Space* (Cleator). G. W. Schumacher, Sannagatan, 21, Kristinehamn, Sweden.

WANTED.—B.I.S. *Bulletin*, Vol. 2, No. 2 (February, 1947), in order to complete set. Please reply—Box 2, c/o B.I.S., 157, Friary Road, London, S.E.15.

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